HUMAN ACTIVITIES AS A CONTRIBUTORY FACTOR IN THE CREATION OF LARVAL HABITATS FOR *ANOPHELES GAMBIAE* IN KISIAN, WESTERN KENYA

By

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DECLARATION

I, Francis Maluki Mutuku declare that this thesis is my original work and has not been presented for a degree in any other university

Signed..... Date.....10/11/04.....

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This thesis has been submitted for examination with our approval as University supervisors

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LIST OF ABBREVIATIONS

CDC	U.S. Centres for Disease Control and Prevention
GIS	Geographic Information Systems
GEE	Generalized Estimating Equations
GOK	Government of Kenya
GPS	Global positioning system
KEMRI	Kenya Medical Research Institute
PCR	Polymerase Chain Reaction
RR	Relative risk
WHO	World Health Organization

DEFINITION OF OPERATIONAL TERMS

Abiotic factors: Non-living, for example climate is an abiotic component of ecosystem

Allopatric: Of populations or species occupying mutually exclusive, but usually adjacent, geographical areas

Biotic factors: Pertaining to life or living organisms

Cryptic species: Species that are difficult or impossible to distinguish by morphological traits

Generalized Estimating Equations (GEEs): is a practical method with reasonable statistical efficiency to analyze data that is correlated and arising from repeated measurements when the measurements are assumed to be multivariate normal

Gonotrophic cycle: Is the feeding, digesting, egg development and ovipositing of female mosquito.

Haemorrhagic: Kind of disease that is characterized by high fever. For example: Yellow Fever and Rift valley Fever.

Larval habitat: The type of aquatic environment in which mosquito larvae are typically found.

Larval instars: Are stages between molts, the first instar is the stage between egg and the first molt

Parasitaemia: A condition in which parasites are and seen in the blood

Poisson distribution: A discrete probability distribution of a random variable representing the number of events occurring randomly and independently at a fixed average rate.

Relative Risk: The ratio of two risks, usually the risk of a disease in a group of individuals exposed to some factor, divided by the risk in the unexposed individuals

Vectorial capacity: It is a function of (a) the vector's density in relation to its vertebrate host, (b) the frequency with which it takes blood meals on the host species, (c) the duration of the latent period in the vector, and (d) the vector's life expectancy.

Sympatric: Closely related species that have overlapping ranges in nature but do not interbreed. Occurring in the same place.

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DEDICATION

This thesis is dedicated to all children under five years in Winam division, Kisumu District

ABSTRACT

Larvae of *Anopheles gambiae* inhabit small water bodies that are often numerous, scattered, sunlit, turbid, temporary, and generally close to human habitations. The productivity of these habitats for adults is poorly known, moreover, little is known about human contribution to habitat existence. This study aimed at determining the impact of human activities on *An. gambiae* s.l productivity in the study area. The potential larval habitats within the study area were surveyed and mapped. A subset of them (34) was selected for daily, longitudinal sampling using maximum density area sampling and census methods, during a period of 25-days in the short rainy season. The results of this study show that larval habitats of *An. gambiae* s.l. can be located and mapped relative to land use, and their origin relative to anthropogenic activity determined. There were variations in overall mosquito production; with burrow pits being the most productive (χ^2=219.03, p<0.0001) while hoof prints, although commonly occupied by larvae (χ^2=21.91, p<0.0001), did not produce any single pupa during the entire study. Human activities contribute significantly in the creation of *An. gambiae* s.l larval habitats (χ^2=36.37, p<0.0001), because the community has uses for the habitats and are valued. The results suggest that ovipositing females do not discriminate well among productive or stable habitats, and that larval mortality mediates pupal production. A clear understanding of the human activities in malaria endemic areas is essential in formulating larval control interventions that are acceptable to the community and sustainable.

CHAPTER 1: INTRODUTION

1.1 BACKGROUND

Malaria poses a major challenge to global public health and exerts an enormous toll in terms of morbidity, mortality and economic underdevelopment. Despite several decades of research and concerted efforts at control, the realization of a malaria-free world remains a dream (Okenu, 1999). An estimated two billion people (more than 40% of the world population) live in areas with malaria (Okenu, 1999). Though in most cases treatable, malaria is responsible for more than a million deaths per year. Annually, 300-500 million cases are diagnosed worldwide (WHO, 2000). Sub-Saharan Africa bears the brunt of this burden and accounts for 90% of malaria cases. The greatest suffering and impoverishment occur among the poor. Malaria affects primarily the poorest and marginal populations in the world. Pregnant women and children under 5 years of age are the most vulnerable (WHO, 1995).

The discovery by scientists that mosquitoes transmitted malaria unleashed a flurry of ambitious public health measures targeting both larval and adult stages of the insect. These measures were designed to stamp out malaria and they did work in some areas such as southern United States where draining of swamps and changing the way land was used was successful in eliminating mosquitoes (Okenu, 1999). The massive worldwide campaign to eliminate malaria in the mid-1960s by the World Health Organization (WHO) had successes, some of which were good. While substantial inroads were achieved in the sub-tropics, controlling malaria in the tropics proved far more challenging. The presence of high parasiteamia levels, high sporozoite rates, prevalence of *Anopheles* species particularly suited to malaria transmission, a climate conducive to

all-year exposure and gradual development of insecticide resistance reduced the effectiveness of the eradication effort. In consequence, eradication plans were largely abandoned in the late 1960s. Malaria prevention efforts have since shifted towards more easily implementable local protection methods, focusing on partial controls of breeding grounds and in particular, on the use of insecticide impregnated mosquito bed nets to minimize infective bites (Kilama, 2000). The landscape ecology of the coastal and lake regions in Kenya provides ideal conditions for the breeding and survival of mosquitoes. The weather and land use in these regions are particularly well suited for the establishment of breeding sites for the mosquitoes. Also man through his activities, for example, agriculture usually creates suitable breeding places for *An. gambiae*. The aim of this study was to investigate the influence of human activities on the creation and maintenance of habitats for *An. gambiae* s.l. and estimate productivity of each type of habitat in the study area.

1.2 RATIONALE OF THE STUDY

While much is known about vector biology and behavior and the malaria parasites, the importance of human behavior in creation of larval habitats of malaria mosquitoes is largely overlooked (Govere *et al.,* 2000). Quite often inadequate attention is given to human as well as vector behaviors before many malaria control programmes are implemented (Githeko *et al.,* 1996a). Failure to consider human behavioral influences in creating and maintaining larval habitats by day-to-day activities has contributed a lot to stable malaria (transmission occurring all year round) conditions in most parts of the tropics

In the study area, little had been done in establishing the abundance of larval habitats, their types, their densities and their productivity. Also no studies have been done to establish the relationship between habitat creation and the human activities involved. Current vector control activity in the area is by community-wide utilization of insecticide-treated bed nets. This study was part of a major project investigating use of source reduction in an area where bed nets are used as control against malaria. This study, carried out in western Kenya aimed to identify and map larval habitats for *An. gambiae* s.l as well as estimate density and productivity of various types of these habitats. Results of such a study would inform the design of anti-larval methods, such as source reduction and microbial or chemical control of breeding sites as malaria control strategies.

1.3 RESEARCH QUESTIONS

1. How is spatial distribution of larval habitats related to settlement patterns?
2. How productive are larval habitats created through human activities?

1.4 HYPOTHESIS

Human activities do not influence abundance of *An. gambiae* s.l larval habitats in the study area.

1.5 OBJECTIVES OF THE STUDY

1.5.1 General objective

To determine the influence of human activities in creation of larval habitats for the malaria vector *An. gambiae*.

1.5.2 Specific objectives

a) To identify and map the types of *An. gambiae* s.l habitats that exist in the study area.

b) To estimate productivity of each type of habitat identified.

CHAPTER 2: LITERATURE REVIEW

2.1 GENERAL EPIDEMIOLOGY OF MALARIA

Malaria is a parasitic disease transmitted by the bite of an infected female *Anopheles* mosquito (Murry and Loper, 1997). The determinants of epidemiology of malaria are immunity and level of transmission. Transmission depends on ecological conditions and vectorial capacity of prevailing *Anopheles* mosquitoes. These mosquitoes require humidity and the correct temperature and in addition surface water for their development and reproduction. These conditions are present year-round in the humid tropics (Brinkmann and Brinkmann, 1991). The intensity of malaria transmission and the degree of malaria risk are distributed in a highly uneven way across any malarious landscape. This is true for every degree of resolution from district or region down to the household and the individual (Carter *et al.*, 2000). Risk factors include location; for example, increased numbers of cases occur in homes near larval habitats, as well as other attributes of houses or living units, among them the structural features and economic, cultural, experiential and genetic characteristics of the occupants (Carter *et al.*, 2000).

Malaria is estimated to be one of the leading causes of mortality and morbidity in Kenya. The disease accounts for 30% of the cases reported in outpatient clinics in the country. *Plasmodium falciparum* is the most common species in Kenya and accounts for 98% of all infections (GOK, 1998). In 1995 for example, the prevalence rate of P. *falciparum*, which is the most pathogenic human malaria parasite, exceeded 50% of the reported cases in outpatient clinics. The parasite infection is associated with a high risk of severe disease and death especially among those with little or no acquired malaria immunity such as children between the ages of 6 to 24 months (GOK, 1997).

2.2 MALARIA VECTORS

About 3,200 species of mosquitoes have been described worldwide with several subspecies belonging to 37 genera all in the family Culicidae. The families are further divided into three subfamilies: Toxorhynchitinae, Anophelininae and Culicinae. Mosquitoes are considered as one of the most medically important species in the class Insecta. The genus *Anopheles* is the most important in tropical Africa as they transmit malaria, which is one of the most debilitating parasitic diseases of humans (James and Harwood, 1979; Service, 1986). In the tropics, mosquitoes are widely distributed with some species such as *An. gambiae* s.s and *An. arabiensis* being sympatric in some areas while in other areas they are allopatric. *An. gambiae* s.s mainly occurs in relatively humid areas while *An. arabiensis* mainly occurs in less humid conditions in Kenya (Minakawa *et al.*, 2002a).

The vectors of human malaria all belong to the genus *Anopheles.* Different species of *Anopheles* transmit malaria in different regions (Gillies and de Meillon, 1968). In Africa, generally members of the *An. gambiae* and *An. funestus* complexes are the important vectors (Beaty and Marquardt, 1996). Members of *An. nili, An. gambiae* complex, *An. moucheti* and *An. funestus* may transmit malaria in the Ethiopian region, while *An. fluviatilis* and *An. stephensi* transmit malaria in western Asia, *An. albimanus* and *An. darlingi* in Mexico and Central America among other regions (Smith, 1973; Service, 1986). In Australasian region *Anopheles farauti* and *Anopheles punctulatus* while in Far East *Anopheles dirus* and *Anopheles fluviatilis* are examples of important vectors. Although there are some 422 *Anopheles* species, only about 70 are malaria

vectors and among these, 40 are important malaria vectors (Lane and Crosskey, 1993). Most of these species have been found to be members of species complexes, each complex consisting of several morphologically identical cryptic species (Beaty and Marquardt, 1996).

2.3 MOSQUITO IDENTIFICATION

Since mosquito larvae from the subfamilies; culicinae and anophelinae have been shown to coexist in the majority of larval habitats in Western Kenya (Minakawa *et al.,* 1999). It is important to recognize the *Anopheles* mosquitoes preferably in all stages and distinguish them from culicines.

2.3.1 Mosquito identification using morphological features

a) Anopheles larvae

Anopheles larvae rest parallel to the water surface held by the assistance of a series of palmate hairs on the dorsal surface of the body. There is no long breathing siphon, but a flat spiracular apparatus surrounding the ends of the tracheal trunks (Appendix I).

b) Anopheles pupae

The pupal stage forms inside the late fourth instar larva, and finally emerges from the last larval skin. The breathing function is transferred from the spiracles at the posterior end of the abdomen to the respiratory trumpets located on top of the cephalothorax. *Anopheles* pupae have respiratory trumpets that have wide opening where they contact the water. Along the posterolateral edges of the abdominal segments, spines (seta 9) can be observed, increasing in size toward the eighth abdominal segment (Appendix II)

c) Anopheles adult

The anopheline adult rests at an angle between 50° and 90° to the surface. They have evenly rounded scutellum, that is, it is arch-shaped, and the hairs on it are evenly distributed along the arc. For female *Anopheles,* the palpi are about as long as the proboscis, the thorax and abdomen are usually with few or no scales while the males have a bushy antenna in appearance, except at the tip where it is swollen and club-shaped (Appendix III).

2.4 MEDICAL IMPORTANCE OF MOSQUITOES

In the tropics, the principal vectors for human malaria belong to the *Anopheles gambiae* and *An. funestus* complexes. Some anopheline species transmit filarial worms such as *Wuchereria bancrofti, Brugia malayi* and *B. timori* all of which cause filariasis in humans. Anopheline species are known to transmit arboviral diseases e.g. in Eastern and Central Africa O'nyong nyong was discovered to be transmitted by *An. gambiae* complex and *An. funestus* (Service, 1986). Mosquitoes mainly in the genus *Aedes* transmit yellow fever and dengue fever in Africa and other tropical areas of the Americas. *Ae aegypti* principally transmits haemorrhagic fevers. Mosquitoes also transmit several forms of encephalitis mainly in the Americas but also elsewhere. These include Eastern equine encephalitis (EEE), Western equine encephalitis (WEE), Japanese encephalitis (JE) and Venezuelan equine encephalitis (VEE). *Mansonia* and *Culex* species have been involved in the transmission of encephalitis both to man and his domestic animals. Viruses known to infect man may also be transmitted by *Psorophora, Wyeomyia, Culiseta* and *Eretmapodites* (Smith, 1973; Service, 1986).

2.5 MALARIA VECTORS AND HUMAN ACTIVITIES

In malaria endemic areas where there is organized human settlement, day-to-day activities such as transport, road and rail construction, construction of houses and rearing of livestock are known to inadvertedly lead to increase in mosquito breeding sites therefore increasing human-mosquito contact, and ultimately transmission of malaria (William Hawley-personal communication). Environmental changes brought about by expanded land use for agriculture, forestry, and human settlements have increased malaria outbreaks and endemicity in many areas (Mutero *et al.*, 1998). An agricultural activity, particularly rice irrigation, has been associated with increased breeding of malaria vectors in the tropics. Rice fields and irrigation canals often produce varying ecological habitats that allow temporal succession of vector species (Service, 1989). It has therefore emerged that environmental factors are important, affecting the behavior of the vector, the vertebrate host, and the parasite itself. Consequently, a number of anopheline species have evolved as efficient vectors in diverse habitats, each with its own unique set of biologic and ecologic requirements.

The type of crop grown also has an important effect on malaria vectors. Rice and other wet crops such as arrowroots have a high risk of malaria vector breeding. This is because their cultivation leads to the accumulation of areas of shallow surface water. Ye-Ebiyo (2000) showed that larvae develop to the pupal stage more rapidly, and produce larger adults where maize pollen is abundant. This was observed in a malaria-endemic region of Ethiopia during a wet season when pollen is abundant. Livestock, especially cattle have also been observed to play a key role in creation of the transient breeding

habitats that are commonly associated with *Anopheles gambiae* (William Hawley-personal communication).

2.6 LARVAL HABITATS AND DISTRIBUTION OF MOSQUITO LARVAE

2.6.1 Types of larval habitats

Mosquito larvae live, grow and mature in aquatic habitats from where they emerge as adults and feed upon hosts in the surrounding areas. The habitats that support breeding by the vectors of human malaria are diverse, and in general, are species specific (Carter *et al.*, 2000). Different mosquito larvae breed in different habitats which may be permanent or semi-permanent standing water with aquatic vegetation (*Culex* species, *Anopheles funestus*), flowing water (open streams in association with vegetation), transient ground pools/ephemeral habitats (mainly *An. gambiae* complex and *Culex* species), tree holes (mainly *Toxorhynchites*) among other habitats and container habitats mainly *Aedes*. In tropical Africa, mosquito larvae and adults are widely distributed with culicines occurring almost everywhere in the continent (Smith, 1973; Service, 1986). Some anophelines such as *An. gambiae* and *An. arabiensis* may be sympatric or allopatric in specific regions. However, the former generally prefers areas with high humidity while the later may occur in dry and arid areas.

Larval habitats may be divided into 4 major types including 1) permanent or semi-permanent standing water including swamps, marshes, ponded streams, ponds, spring-fed pools and lakes, 2) flowing water (stream associations) including open streams in association with vegetation, open gravel beds in braided streams, 3) transient ground pools including various short-lived accumulations of water in relatively shallow hollows,

usually filled by rainwater, and 4) container habitats which can be of various kinds including, both natural and artificial. Natural container habitats include rock pools, tree-holes, leaf axils, fallen leaves, coconut shells and snail shells. Artificial containers include discarded tins, cans, pots, bottles and motor tyres (Goma, 1966; Service, 1986; Lane and Crosskey, 1993; Clements, 1999).

2.6.2 Larval habitats for Anopheles gambiae

Some mosquito species may utilize all sorts of habitats both all natural and artificial. Some mosquito species are however specific in their habitat choice. *Anopheles gambiae* prefers temporary small sunlit pools, drains and ditches, rice fields and grassy swamps (Goma, 1966; Gillies and de Meillon, 1968; Gimnig *et al.*, 2001). Habitats are often created by human and animal activity wherein larvae are found in small depressions such as footprints, the edges of bore holes and borrow pits, roadside puddles formed by tyre tracks, domestic water containers, irrigation ditches and other artificial bodies of water (Gimnig *et al.*, 2001). Recent studies (Minakawa *et al.*, 1999; Gimnig *et al.*, 2001) showed that small size habitats, the presence of turbid water and algae, and the absence of emergent vegetation are associated with presence of *An. gambiae* larvae.

2.7 AQUATIC BEHAVIOR OF MOSQUITO LARVAE

Mosquito larvae of all species are functionally aquatic and pass through four larval instars or intermolt developmental stages, each one followed by a molting of cuticle to allow growth. The time of larval development is dependent upon species, temperature and availability of food (Kreir, 1980; Bayoh and Lindsay, 2003). When 'resting' the

larvae is attached to the surface film of water, either by air tube near the end of abdomen (culicines and toxorhynchitines) or by palmate hairs along the entire length of the body (anophelines) and may intermittently filter feed in this position. Mosquito larvae may dive to the bottom in order to browse on deeply submerged food if it is insufficient at the surface, returning to the surface periodically for oxygen (Kreir, 1980).

Larvae will dive to bottom of the habitat if disturbed by vibrations or sudden reduction in light density and usually swim towards darkness. This submergence is usually in response to diminution in light intensity and sudden mechanical vibrations of water surface. In the tropics, mosquito larvae may avoid the high surface water temperatures by submerging to cooler areas. Period of submergence is affected by factors such as age, temperature, oxygen content of water and morphological modifications of tracheations. Mosquito larvae will often aggregate at darker areas even when at the water surface. Culicines generally are more prone to dive and to choose dark places than are anophelines; *Mansonia* and *Coquilettidia* for example, remain attached to the submerged parts of aquatic plants, obtaining oxygen from tissue air spaces (Lane and Crosskey, 1993).

2.8 LARVAL SAMPLING PROCEDURES

The larval ecology of African malaria vectors has been a neglected area of vector research. Entomologists have been reluctant to study larval ecology (Service, 1976). Several reasons can be attributed to this lack of ecologic studies on anopheline larvae. Firstly, malaria control in Africa traditionally has been directed at the adult stages; studies of larval ecology have been thought to be irrelevant by some workers. The second

reason for lack of larval studies of *An. gambiae* is methodological. Until the development of Polymerase Chain Reaction (PCR)-based diagnostic tool by Scott *et al.,* (1993), no method existed for identifying early instars of this species complex. A third reason is the difficulty involved with larval sampling from aquatic habitats in the field, particularly when many larval habitats are not permanent (Minakawa *et al.,* 1999). Population measurements are often needed to demonstrate the factors regulating populations of *An. gambiae* under different environmental conditions and estimates of larval populations of *An. gambiae* are often required in control programmes. The small size of the most important habitats makes them impossible to sample by many of the normal entomological methods such as dragnets, dredges, sampling cylinders, and cages (Service, 1971).

The most common sampling procedures that are used include dipping, netting and paletting. Dipping method is the most frequently used in larval sampling especially in large water bodies, however the collecting device will depend on the size and type of habitat (WHO, 1975). Dippers may range from enamel bowls, frying pan and ladle. Netting method involves sweeping the water surface using a larval net, mainly along the edge of streams and wells. Devices such as pond nets and hand nets are used. In the paletting method, the larvae are collected using a device with very fine mesh size, which is connected to a long handle. The device may be quickly skimmed through the water surface or inserted into vegetation and the larvae obtained may be washed into a tray and then picked from the tray using a pipette. In much smaller habitats such as animal hoof prints, mosquito larvae may be picked directly from habitat using pipette (Gimnig *et al.*, 2001; Minakawa *et al.*, 1999). The behavior of the species being studied however has to

be taken into account. Reliable quantitative sampling of larval density however is difficult to achieve due to i) mosquito larvae are not randomly distributed in habitats, ii) breeding places vary in size and shape and may change from time to time and iii) behavior of larvae in breeding habitats varies. During larval surveys, it is also important to collect the following information: approximate surface area, depth, breeding place whether shaded or unshaded, physical aspects of the habitat and vegetation around the breeding habitat (WHO, 1975).

2.9 ENVIRONMENTAL FACTORS THAT DETERMINE LARVAL ABUNDANCE

Once eggs are laid, their survival and consequently abundance of larvae is dependent on abiotic and biotic factors.

2.9.1 Climatic factors

a) Temperature

Mosquito larval development is temperature dependent (Clements, 1992; Bayoh and Lindsay, 2003). Mosquito larvae require optimal temperatures for development to occur. Warmer temperatures however have been shown to increase the rate of larval development despite shortening their mean daily survivorship (Yoganathan and Rom, 2001). Temperatures between 15°C-30°C may influence abundance of mosquito larvae by shortening the gonotrophic cycle and increasing the number of blood meals taken and the number of times eggs are laid by adult mosquitoes. This may increase larval abundance in breeding habitats in the absence of other larval mortality causing factors. A

small temperature rise from 19°C to 21°C may shorten the gonotrophic cycle from 4 to 3 days (Martens *et al.*, 1996; Malakooti *et al.*, 1998). Other studies (Alto and Juliano, 2001) have also shown that development time of larvae decreases with increased temperature, though increased temperatures may result in greater egg mortality. At temperatures below 15°C, the aquatic stages of tropical anophelines fail to develop or breed (Gillies and DeMeillon, 1968). This may limit larval development in colder areas or habitats resulting in low larval densities.

b) Precipitation and Relative Humidity

Mosquitoes breed in water habitats and require just the right amount of precipitation in order to breed. However too much rainfall, or rainfall accompanied by storm conditions flushes away larvae. Not only the amount and intensity of precipitation, but also the time in the year, whether in the wet or dry season, would affect survival of mosquito larvae and thus regulate their abundance. Seasonal changes in abundance of mosquito larvae, for example, are associated with rainfall (Grillet, 2001). This association is mainly attributed to availability of larval breeding habitats. Generally, moderately frequent rainfall with long periods of sunshine increases prolific breeding of mosquitoes (WHO, 1975). *Anopheles* population is very sensitive to rainfall (Malakooti *et al.*, 1998), which increases the availability of breeding habitats. In western Kenya, for example, rainfall amounts of 150 mm per month lead to rapid expansion of *An. gambiae* population (Githeko *et al.*, 1996b).

c) Wind

Gravid female mosquitoes require stable environment to lay eggs (Clements, 1999). Strong winds may, however, prevent gravid female mosquitoes from ovipositing. Though breeding habitats may be available, disturbance by strong winds will prevent oviposition hence habitats in such areas may have low densities of mosquito larvae. Mosquito larvae are also rarely found in waters with strong currents or waves (Goma, 1966). Strong winds may also extend the length of the flight range of adult mosquitoes.

2.9.2 Physiochemical properties of water

Physiocochemical properties of water such as water temperature, ammonia nitrogen, dissolved oxygen and nitrate nitrogen can act either synergistically or singly to limit or favour larval abundance. These were found to be the best predictor variables associated with the immature abundance, nearly always consistent in their effects within and between seasons (Rajavel, 1992; Robert *et al.*, 1998). These studies found that application of synthetic nitrogenous fertilizers to the rice fields resulted in increase of concentration of ammonia nitrogen and a subsequent increase in nitrate nitrogen level in the rice field water, during which an increase in the density of larval instars was observed. Fields treated with inorganic fertilizers (N, P, K) had significantly higher population densities of mosquito immatures than fields treated with organic manures.

Salinity and dissolved oxygen have also been found to be strongly associated with the spatial distribution of *An. aquasalis* and *An. oswaldoi* (Grillet, 2001). Mutero and Mosha (1982) reported that *An. merus* larval density increased with increase in salinity up to an optimum of 45% after which further increase in salinity resulted in lower larval

densities. Water pH indirectly affects larval abundance by influencing the microflora and microfauna, which are used as food by mosquito larvae (Goma, 1966).

2.9.3 Food resources

In the tropics the driving variables determining the presence or absence of some anopheline species are the hydrology and habitat composition in terms of live aquatic micro and macrophytes and detritus (Rejmankova *et al.*, 2000). Food availability is one of the factors that may influence larval abundance. Mosquito larvae are filter and collector feeders and feed on other microorganisms (Clements, 1999). In habitats with abundant food resources, intra-specific competition for food resources may be reduced and may support higher larval abundance. It is reasonably assumed that in large water bodies such as rice fields' food might not be the limiting factor to larval development, but that predators might be the regulating factor. Intraspecific competition for food resources however might be a major mortality factor in container breeders. It reduces survivorship, pupal mass and may produce increase in growth retardants (Lounibos *et al.*, 1984). This may result in larval mortalities hence negative effect on larval density.

2.9.4 Vegetation or Floral factors

Macrophytes growing in breeding waters may have positive or negative effects on larval abundance. Macrophytes play a positive role in increasing the abundance of mosquito larvae by providing protection from inimical forces such as predators, currents and waves (Begon *et al.*, 1990). Rice paddy height may negatively influence larval abundance. Mutero *et al.* (2001) and Robert *et al.* (1998) found a negative association between rice

plant height and *An. arabiensis* larval abundance with the highest density of immature mosquitoes occurring after rice transplantation and decreasing with increase in height of rice. They found that fields planted with normal spacing of paddy had significantly higher populations of culicine and anopheline immatures than the fields planted with wider spacing of paddy. Light intensity, measured at the water surface, was inversely related to the development of plant canopy and the results suggested that plant canopy does not inhibit oviposition by mosquitoes in the early stages of paddy growth, but it was responsible for the decline in the populations in the later stages of paddy growth (Victor and Rueben, 2000).

Higher larval densities were observed in the groups characterized by relatively short emergent vegetation with a canopy cover of 25-50% over the breeding site. Savage *et al.* (1990) also reported association of *An. albiminus* with the presence of floating plants, particularly *Eichhornia crassipes*. Vegetation around breeding habitats provide protection and resting places to adult mosquitoes (Rejendran and Rueben, 1991) and may enhance their survival. Vegetation, in addition to providing food to the larvae, acts on the environment of the immature stages by influencing temperature, evaporation, chemical content, light intensity, oxygen supply and attachment sites (WHO, 1967). Dense vegetation around breeding habitats may also limit breeding of *An. gambiae,* as this species prefers open and sunlit habitats.

2.9.5 Topography

Topography indirectly affects larval abundance by determining the availability of larval breeding habitats. In hilly or highland areas, breeding sites are mainly concentrated at the

valley or foot of the hills due to force of gravity, which moves storm/rainwater to relatively flat or lowland areas. Breeding sites are more common on the valley floor than steep valley slopes, while the colder nights at higher altitudes may restrict the dispersal of adult mosquitoes from these sites. This leaves the steep areas with few breeding sites (WHO, 1975).

2.9.6 Edaphic factors

Soil type may indirectly determine larval abundance by influencing the availability of breeding habitats. Soils, which easily retain water, (such as clay soil) may have higher numbers of breeding habitats when it rains than soils in which water percolates and/or evaporates fast. In this way, soil types may thus influence the fluxes of water into and out of aquatic habitats, which in turn determines the size, stability and dynamics of larval breeding habitats. Local hydrologic characteristics may produce different types of larval habitats resulting in different mosquito species distribution and productivity. Eggs of some mosquitoes especially *An. gambiae* may also have higher chances of surviving in moist soils during short dry periods (Minakawa *et al.*, 2001). In this way, soils that maintain moisture for long periods may support higher larval densities of some species.

Microorganisms for example cyanobacteria in soil in breeding habitats may produce volatiles, which may act as oviposition cues. In this way, they may deter or attract gravid female mosquitoes (Rejmankova *et al.*, 1996). Habitats with oviposition attractants may thus have higher larval abundance of specific species of mosquitoes.

2.10 MALARIA CONTROL

Control of malaria encompasses a variety of measures that include the reduction of the mosquito population, the minimization of the number of infective bites for a given mosquito population and use of anti-malarial drugs. The Global Malaria Control Strategy was endorsed by a Ministerial Conference, which took place in Amsterdam in October 1992. In this conference, endemic countries agreed to initiate and/or strengthen malaria control efforts in order to reduce the burden of the disease at all levels (WHO, 1993). The overall global malaria goal is the prevention of mortality and reduction in morbidity and social and economic loss due to malaria, through the progressive improvement and strengthening of local and national capabilities for malaria control at national, district and community levels.

In control of mosquitoes, either the larvae or the adults are targeted. Adult control involves use of insecticide treated nets, residual spraying, epidemiological surveillance and screening, and personal protection measures.

2.10.1 Malaria control strategies in Kenya

Efforts to control malaria have hitherto been sporadic, piecemeal and, despite some successes, have not effectively reduced or even decelerated overall disease rates. Indeed, both illness rates and epidemic outbreaks are on the increase (GOK, 2001). The National Malaria Strategy paper outlines four strategic approaches to malaria control; Clinical management, providing prompt and effective treatment, management of malaria and anemia in pregnancy, and vector control. These policy guidelines for malaria control put substantial bias on vector control through use of insecticide-treated nets. Other vector

control methods of public health significance such as source reduction through larval control, that is, by use of carnivorous fish for example *Oreochromis spilurus spilurus*, larvicidal chemicals and filling in or draining breeding sites have largely been sidelined. The emerging resistance to residual insecticides is now threatening the policy bias on their use (Chandre *et al.,* 1999; Zaim and Guillet, 2002).

2.10.2 Chemotherapy

In malaria endemic areas, provision of easy access to treatment is the main approach to malaria control. This approach has been effective in parts of Southeast Asia, such as Thailand, although it has probably had less impact on mortality from malaria in Africa (Greenwood, 1997). In areas of low malaria endemicity, radical treatment of cases of clinical malaria with primaquine is often used in an attempt to reduce transmission, although the effectiveness of this practice is uncertain. In highly endemic areas of Africa, radical treatment is rarely attempted and treatment of symptomatic infections with chloroquine or pyrimethamine-sulphadoxine is unlikely to have any effect on transmission, as these drugs have little action on gametocytes (Greenwood, 1997).

2.10.3 Larval control

Most practical methods aiming at the reduction of vector densities require the treatment of vector breeding places, leading to their elimination or to a considerable reduction of breeding at the sites. Their effect on malaria transmission will therefore depend on the relative importance of the treated breeding places in maintaining vector density. These methods include all forms of larval control:

2.10.3.1 Environmental management

This involves the modification of the environment to prevent mosquito breeding by eliminating breeding places or altering the habitat to reduce the potential numbers of larvae that could survive (source reduction). Mosquito breeding sites that are impossible to alter or eliminate may be treated with an appropriate larvicide. With proper planning, design and maintenance, environmental management can prevent, reduce or eliminate mosquito breeding. Long-term costs are relatively low, although initial expenditure may be high (Najera and Zaim, 2002).

Environmental manipulation involving land, water, and physical characteristics such as draining, filling, ditching, flushing, and water management are the most effective and permanent methods to reduce the breeding places of several disease carrying mosquito species. These are the classical methods of malaria control, which may be used for all mosquito breeding in general or targeted to the specific breeding places of malaria vectors of local importance (species sanitation) (Najera and Zaim, 2002).

Drainage is used to eliminate standing water where mosquito larvae can live. It can be applied to various sizes of standing water areas. In addition to mosquito control, drainage is often valuable in reclaiming land for other uses such as agriculture, getting timber for housing, commercial uses and so on. Contour draining, for example, is an accepted practice in agriculture to prevent erosion and standing of water from damaging crops and to allow better access for tillage. Many areas of standing water are manmade by earth moving activities during construction, mining and quarrying among others (Najera and Zaim, 2002). Draining dries up these areas. When drainage is considered for swamps,

marshes, and other larger bodies of water, the effects on wildlife and the natural environment must be considered.

Ditching of one type or another is usually involved in drainage. Ditches should be of sufficient size and grade to carry peak loads of water yet maintain a flow at low water levels to avoid standing water; erosion-resistant shape and construction materials; minimal maintenance requirements and capable of delivering water to a suitable area.

Filling raises the level of soil up to grade so that proper run-off of water occurs and standing water providing mosquito larval habitat is eliminated. This is a useful technique for small depressions, vehicle ruts, depressions left by uprooted trees and others.

Water management, which involves raising and lowering water levels, may impact the biology and habitats of mosquitoes and the aquatic weeds that protect mosquito larvae from predators; mosquito populations can be reduced significantly. During periods of heavy rainfall, dams hold back water due to flooding down stream. This increase in lake level often causes flooding of the eggs laid in the soil by floodwater. Many of these eggs may hatch. However, dropping the water before the larvae can mature removes water from their breeding area and causes them to die. Alternatively, if the larvae fall with the lowering water level, they will be exposed to fish and other predators (Rose, 2001). Anopheline species which may breed in the weedy backwaters can also be controlled by dropping the water levels at various times. This may also control many of the aquatic weeds, which protect developing larvae (Rose, 2001).

Larviciding is the application of chemical or other product to a water source to kill the aquatic stages of the mosquito. Controlling the larvae is more effective than adulticiding as it kills the mosquitoes at a stage before they become medically important. Due to

inability of the larvae to move and avoid chemicals applied, larviciding therefore is an efficient method of controlling mosquitoes (Killeen *et al.*, 2002).

2.10.3.2 Biological control of mosquitoes

a) Microbial larvicides and other parasites

These include microbial larvicides which are bacteria that are registered as pesticides for control of mosquito larvae in outdoor areas such as irrigation ditches, flood water, standing ponds, woodland pools, pastures, tidal water, fresh or saltwater marshes, and storm water retention areas. Duration of effectiveness depends primarily on the mosquito species, the environmental conditions, the formulation of the product, and water quality. Microbial larvicides may be used along with other mosquito control measures. The microbial larvicides used for mosquito control are *Bacillus thuringiensis israelensis* (*Bti*) and *Bacillus sphaericus*. *Bti* is a naturally occurring soil bacterium registered for control of mosquito larvae. Mosquito larvae eat the *Bti* product that is made up of the dormant spore form of the bacterium and an associated pure toxin. The toxin disrupts the gut in the mosquito by binding to receptor cells present in insects, but not in mammals. These microbial larvicides are essentially nontoxic to humans, wildlife and non-target organisms.

Fungal infections such as *Coelomomyces, Metarhizium* and *Culicinomyces* spp. are also known to cause mortalities in mosquito larvae and may adversely affect larval densities. Infection of mosquito larvae with nematodes and *Coelomomyces* and epibionts considerably slowed down movement of the mosquito larvae and consequently reduce their ability to escape from various predators (Service, 1973).

b) Mosquito larvae predators

Generally, mosquito larvae predators have been shown to play an important role in regulating vector populations (Mogi, 1993). The predators include invertebrates and macro-invertebrates such as water beetles, beetle larvae, dragon fly larvae, water spiders and other mosquito larvae. However only a few of these have been manipulated to provide greater control than would occur normally in nature. *Toxorhynchites*, which are top feeders, have been used extensively in the control of mosquito larvae. The mosquito fish, *Gambusia affinis* and *G. holbrooki* have been used worldwide for mosquito control (Yaghoobi-Ershardi *et al.*, 2001). This fish species is commercially available and are introduced into ponds and other permanent water where they feed on mosquito larvae. These fish are most effectively used in man-made bodies of water that do not connect with natural waters. Since this fish species is a top feeder its efficiency might be reduced as they may fall prey to other fish species and may not be suitable for all waters.

2.10.4 Integrated Vector Management

Mosquito control in Africa and other parts of the world has evolved from reliance on insecticide application for control of adult mosquitoes to integrated vector management programs that include surveillance, source reduction, larvicides and biological control. Integrated vector management in control of mosquito larvae involves control of mosquitoes using more than one control method. This might involve a combination of biological, chemical and environmental methods and educating the public on ways of controlling mosquito larvae (Rose, 2001). It has been defined as the process consisting of

balanced use of cultural, biological and chemical procedures that are environmentally compatible and economically feasible to reduce pest and disease-vector populations to a tolerable level (Rose, 2001).

CHAPTER 3: MATERIALS AND METHODS

3.1 STUDY SITE

The study was conducted in Kisian, a rural village located 10 km west of Kisumu town in Nyanza province, western Kenya (Fig. 1). Administratively this village is in Korando B sub-location, Central Kisumu location, Winam, division Kisumu district. The study site covers an area of 7.7 km^2 and has a population of 5,412 people (GOK, 2000). Rainfall occurs year-round with two main peaks; the long rains falling between March-April, and the short rains between November-December. Periods longer than 15 days without rainfall are rare in the Kisumu area, which averages 1500 mm of rain per year (Beier *et al.*, 1990). Malaria is highly endemic in this region, with transmission occurring throughout the year.

3.1.1 Study population

Ninety- nine percent of the study population is of the local luo ethnic group. Most are subsistence farmers who cultivate maize, sorghum, cassava, millet, and vegetables. Some animal husbandry of cattle, goats, sheep or poultry is evident. Other human activities include fishing in lake Victoria and local marketing of food and grain. A small percentage of the population works in Kisumu town and commute daily.

3.2 MAPPING OF LARVAL HABITATS

Identification and mapping of all stagnant water bodies in the study area was done from November 19, 2002- November 22, 2002. A total of 104 habitats were identified and mapped using a Global Positioning System (GPS) machine. Visual search in all the habitats was done to identify those with larvae.

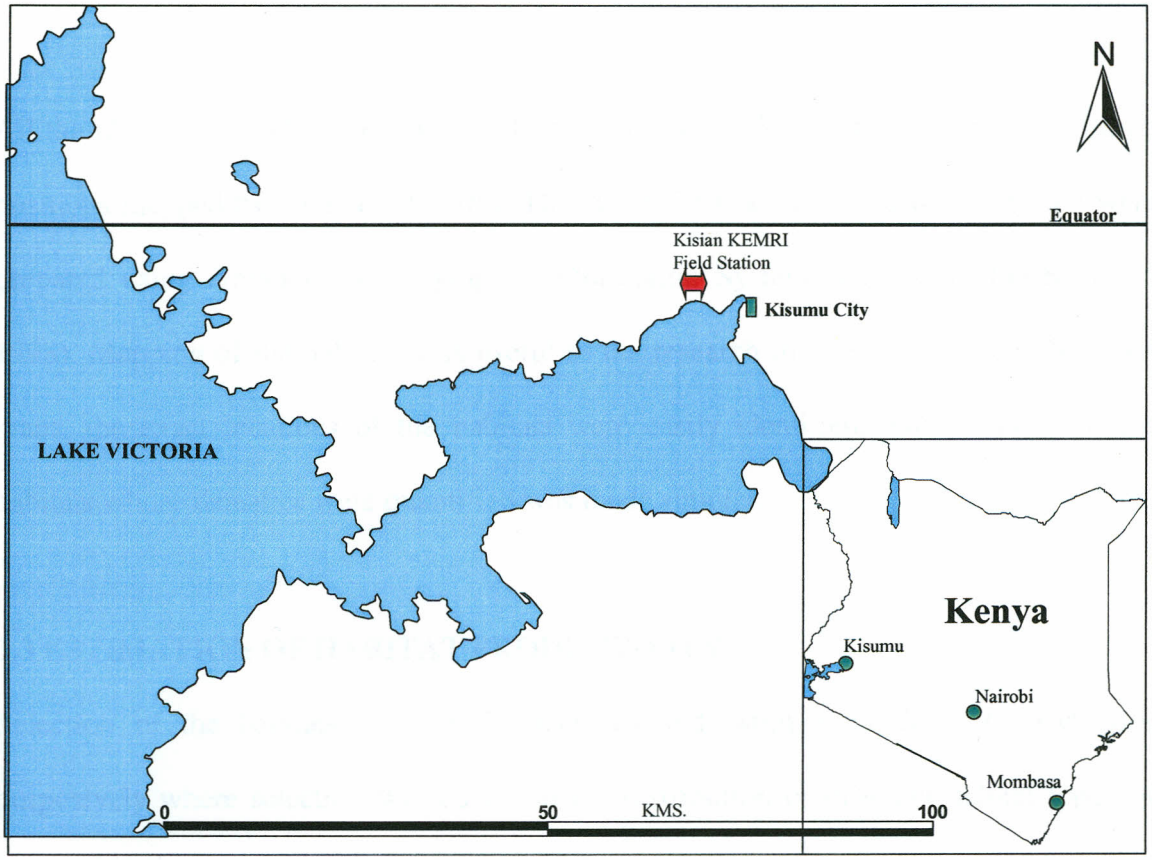

Figure 1: Location of the Kisian study site, Kisumu district, Western Kenya

All the identified habitats were ascribed unique location identification numbers and their positions mapped by a hand-held GPS. Thereafter the base-maps for the study site were prepared using ArcView, a Geographic Information System (GIS) (Hightower *et al.,* 1998). Mapping of the habitats was useful to the research in two ways: Using the base-maps, the exact locations of the habitats were easily identified, and sampling of the habitats whose densities were quantified was made simpler.

3.3 ESTIMATION OF HABITAT PRODUCTIVITY

Selection of the habitats to quantify densities and estimate productivity was done purposively where selection was based on the distribution of different habitat types. A total of 34 habitats were selected from the 85 found to be positive of *An. gambiae* s.l larvae.

3.3.1 Estimating larval density

Sampling of larvae in each of the selected habitats was done using an "area sampler" (Walker *et al.,* in preparation). Sampling was conducted in months of November and December (during short rains) when almost all transient habitats were active. To obtain quantitative data, the 'area sampler' employed was placed in the area to be sampled as quickly as possible, in order to avoid frightening the larvae away. The area sampler used in this study was an open-ended 10 cm diameter and 12.5 cm high, transparent plastic cylinder (Plate 1). Thus, in this case the amount of surface that could be sampled was 78.5cm^2. At every habitat, the sampler was pressed in the substrate such that it could support itself or if this was not possible, it was held firmly down in the mud or sand until

sampling was done. Most of habitats had mud as the substrate but in a few, the substrate was sand. All larvae trapped inside the sampler were pipetted into a petri dish for counting. Plastic pipettes were used to collect the larvae individually.

Plate 1: A picture showing how the area sampler was used

After ensuring all the *An. gambiae* s.l larvae enclosed by the area sampler were scooped in the dish, they were counted and sorted by instars according to WHO (1975) and, returned into the habitat. The numbers of the various larval stages as well as the total number of larvae were recorded. To get maximum larval density the 'area sampler' was placed on that point in the habitat where the maximum number of larvae was observed. This procedure was done daily for each of the 34 habitats for 25 days. The length, width and depth were measured for each habitat. Length and width were used to estimate the surface area of each habitat. Only anopheline larvae were counted.

3.3.2 Pupal productivity

Unlike the estimation of larvae density where an area sampler was used, in estimating pupal productivity, pupa census was done. A visual check in the entire habitat was done in each habitat daily for the 25 days a period long enough to allow two cohorts of larvae to become adults and the pupae present were collected using a wide mouthed pipette. This procedure, including quantification of larvae took a minimum of 25 minutes each spent with sample to ensure adequate coverage, and some samples required up to 45 minutes to complete.

The pupae collected were counted and placed in small tubes with water and transported to the laboratory. In the laboratory, the pupae were held in paper cups to allow for emergence, followed by morphological identification of adults to species and separation of anopheline from the culicines.

3.4 DATA ANALYSIS

Data analysis was performed using EPI INFO 6.01 (Centres for Disease Control and Prevention, Atlanta, GA) and the SAS system for windows, version 8.01 (SAS, Inc., Cary, NC). Productivity of the different types of habitats was estimated by two main methods: i) by comparing larval densities and pupal numbers sampled during the study time (herein referred to as cumulative productivity). ii) by comparing larval densities and pupal production on daily basis for the entire study time (herein referred to as daily productivity). Daily and cumulative productivity of habitats, as measured by the total larvae or pupae, were compared among habitat types by Poisson regression using SAS version 8.01 (SAS Institute, Cary, NC, USA). A model was used to compare the

differences larval productivity per habitat type while another two models were used for comparing the differences pupal productivity per habitat type and per unit area. For daily productivity, the same GENMOD (Poisson regression) procedures were used with repeated measures function to adjust for correlation between visits since sampling was done on daily basis. The comparisons were done with assumption that the larvae and pupae exhibited Poisson distribution. Variables included in each model were habitat type, average habitat size during the sampling period, stability and distance to the nearest house. Habitat size, stability and distance to the nearest house were categorized as dichotomous variables for analysis. The cut-offs for each variable were selected to maximize the number of habitats within each category.

3.5 ETHICAL CLEARANCE

Clearance of this research was obtained from the Ministry of Education, Science and Technology, Kenya. The Larval Ecology Project, under which this research was carried, was approved by the institutional review boards of the Kenya Medical Research Institute (KEMRI) and the National Centres for Infectious Diseases, Centres for Disease Control and Prevention (CDC), Atlanta, USA.

CHAPTER 4: RESULTS

4.1 HABITAT TYPES AND DISTRIBUTION

A total of 104 potential habitats were encountered and mapped during the initial survey of the study area. Using the perceived cause of habitat creation and habitat hydrology, all the habitats encountered were classified into 6 main types as follows: burrow pits, drainage canals, tyre tracks, hoof prints, rain pools and stream beds (Fig. 2). Among these, 82% had Anopheline larvae either occurring singly or together with culicine larvae

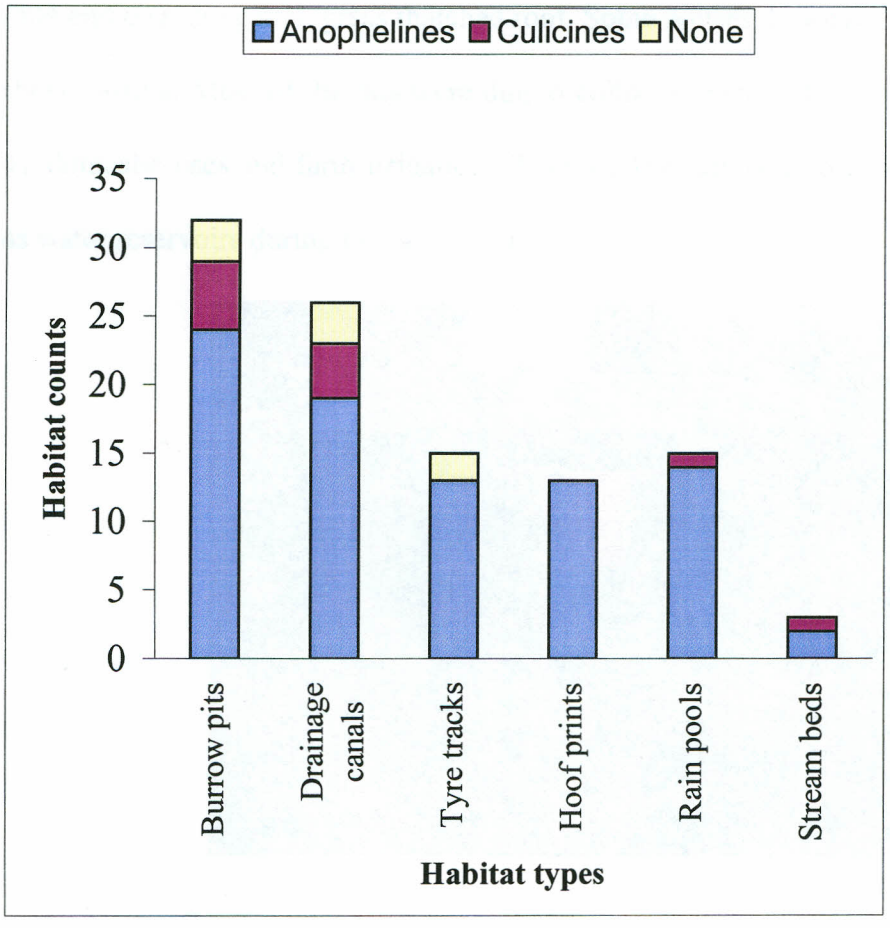

Figure 2: Habitat types and abundance of mosquito larvae in 104 aquatic habitats surveyed in Kisian area, western Kenya, in November 2002

and 83 % were man-made habitats. Burrow pits were the most abundant type of habitat representing 30.8 % of the total habitats identified while streambed habitats were the least with only 3%. The specific habitat types identified in the study area were : -

a) *Burrow pits*-this group consisted pits of different sizes and varying depths. All the pits identified were created through human activities. A good number of these pits were dug when making mud walls (houses) (Plate 2 and Plate 3). The most common type of house in the community is the traditional Luo hut that has a wooden framework plastered with mud and cow dung and, grass thatched roof. Some houses, however, have corrugated iron sheet roofing. Most of the pits were dug to collect rainwater for domestic animals (Plate 4), domestic uses and farm irrigation (Plate 5). The relatively big and deep pits are used as water reservoirs during the dry seasons.

Plate 2: Burrow pit: Dug to get mud for house construction

Plate 3: Burrow pit: Dug to get mud for brick making

Plate 4: Burrow pit: Dug to collect water for watering cattle

Plate 5: Burrow pit: Dug to collect water for domestic use

b) *Drainage canals*-These include terraces, ditches, and trenches which are dug either to drain water, in an attempt to divert running water that would otherwise flood farms and destroy crops or remain stagnant around houses. Others are dug purposively to prevent soil erosion (Plate 6).

Plate 6: Drainage canal in maize garden

c) *Tyre tracks*-the study area is traversed by several feeder roads that join the main Kisumu-Busia highway, which cuts across the study area. These feeder roads are used for general transport purposes in the community, which includes transport of farm produce to Kisumu town. In almost all the feeder roads, there are certain points where vehicles, ox-carts, or hand-pulled carts have made tyre tracks (Plate 7).

Plate 7: Tyre tracks formed by motor vehicles

d) *Hoof prints*- animal husbandry of cattle, goats, sheep or poultry is practiced in the community. Cattle are the principle cause of hoof prints. Because of the nature of the soil, human footprints are commonly discernable on the ground and more especially during the rain season. Both hoof and footprints are mainly found around rain pools, ponds, at the edges of the river and along the paths used by people and cattle (Plate 8)

Plate 8: Hoof prints formed by cattle

e) *Rain pools*- these are depressions which are manmade, natural or a combination of both. It was difficult to determine the actual cause of creation through observation. Continuous use by cattle as a passage route combined with soil erosion could perhaps explain the creation of some of these habitats (Plate 9).

Plate 9: A rain pool that is naturally formed

f) *Streambeds*-there is a seasonal river cutting across the study area and another permanent river on the west side of the study area. No habitat was identified along the permanent river. Habitats were identified at some points along the seasonal river (pools of water left by the receding river) (Plate 10).

Plate 10: A streambed (Pool of water left by a receding river)

Assuming rain pools and streambeds were naturally occurring habitats in this study, comparison between abundance of natural and manmade habitats was done using summary chi square statistic by Mantel Haenszel stratified cross-tabulations. Results showed manmade habitats were more abundant compared to natural ones (χ^2= 36.37, df=5, p<0.0001).

4.2 HABITAT PRODUCTIVITY

A total of 841 sampling efforts were made during the 25-day period of the study (Table 1). Habitat productivity was determined daily for a total of 34 habitats by larval sampling and pupal census. Other than rain pools, the rest of the habitat types were man-made (representing 82% of the total habitats sampled). A total of 4615 *An. gambiae* s.l larval counts and 932 pupal collections were made from the 34 habitats during the 25 day sampling period (Table 2). A breakdown of the number of each habitat type investigated and the number of times the habitats were sampled is provided in table 1.

Table 1: Number of habitats sampled and number of sampling efforts per habitat type

Habitat type	N*	Number of samples done**	% Samples done
Burrow pits	8	197	23.42
Drainage canals	5	125	14.86
Tyre tracks	8	199	23.66
Hoof prints	7	171	20.33
Rain pools	6	149	17.72
Total	**34**	**841**	**100.00**

**N= Number of habitats per habitat type*
***Number of samples done= Number of samples taken from a given habitat type during the sampling period*

4.2.1 Larval density

Burrow pits produced the highest number of absolute larval counts followed by rain pools, while hoof prints produced the least number of larvae (Table 2). However, comparison of daily mean density larval among the habitat types showed rain pools to be

the most productive habitat type with a mean of 8.52, followed by burrow pits 6.79. Hoof prints were the least productive with a mean of 2.02 (Table 2).

Similarly, rain pools with mean larvae of 211.67 and burrow pits (mean=167.125) were more productive than tyre tracks (mean=126.75) when their cumulative mean total larval productivity for the 25-day period was compared. Drainage canals (mean=127.02) and tyre tracks produced the same mean numbers of larvae while hoof prints (mean=49.43) were the least productive (Fig. 3).

Table 2: Total larval production, mean cumulative larval production and daily larval production in 5 different habitat types for a period of 25 days

Habitat type	**Total larval numbers**	**Mean cumulative larval production per habitat (±95% CL)**	**Mean daily larval production per unit area (±95% CL)**
Burrow pits	1337	167.12 (175.00)	6.78 (3.33)
Rain pools	1270	211.67 (270.87)	8.52 (3.83)
Tyre tracks	1014	126.75 (99.46)	5.09 (2.47)
Drainage canals	637	127.20 (174.50)	5.08 (2.90)
Hoof prints	357	49.43 (70.68)	2.02 (2.03)
Total	**4615**		

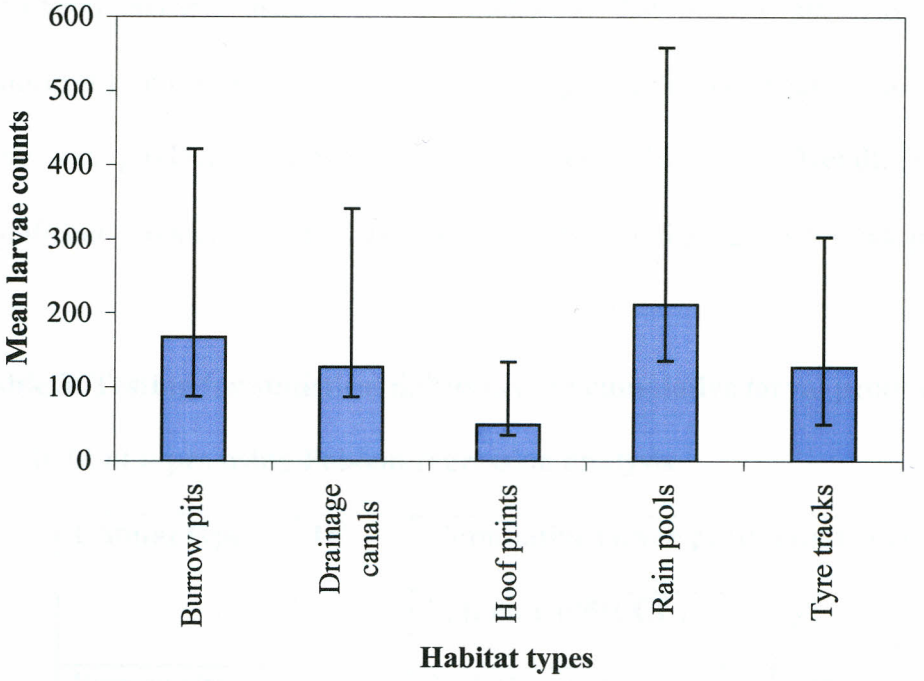

Figure 3: Mean cumulative larval productivity by habitat types during sampling period

Assuming that mosquito larval populations exhibit a Poisson distribution or a negative binomial distribution, two models were constructed to test differences in larval densities in the different habitat types using the GENMOD procedure in SAS (SAS Institute). The first larval model tested statistical differences in total larval production among the habitat types without regard to habitat area because maximum area density sampling was done. Total larvae as a variable comprised of all the four larval instars and was the dependent variable in this model with habitat type being explanatory variable. Differences in larval production were computed by comparing each habitat type with a reference group and in my larval models, tyre tracks were arbitrarily chosen as my reference group. Poisson

regression analysis using this model showed that burrow pits and rain pools were significantly more productive compared to tyre tracks. Drainage canals and hoof prints were less productive compared to tyre tracks (Table 3). Overall, habitat type was significantly associated with larval productivity (Wald χ^2=261.97, df=4, p<0.0001).

Table 3: Testing for statistical differences in cumulative larval productivity among habitat types using Poisson regression analysis

Habitat type	Df	Cumulative larvae productivity per habitat		
		Estimate (95% CL)	χ^2	P
Burrow pits	1	0.13 (0.04-0.22)	8.86	0.0029
Drainage canals	1	-0.21 (-0.32-(-) 0.11)	16.29	<0.0001
Hoof prints	1	-0.75 (-0.87-(-) 0.62)	133.25	<0.0001
Rain pools	1	0.25 (0.15-0.34)	26.92	<0.0001
Tyre tracks	0		-	-

Df= Degrees of freedom

The second larval model used repeated measures to adjust for correlation between different visits to the same habitat since sampling was being done on a daily basis. Unlike the first model, which tested differences in cumulative larval production among habitats, this model looked at differences in daily larval production without controlling for area. Repeated measures Poisson regression results for this model indicated that rain pools were by far the most productive habitat type. Generalized Estimating Equations (GEE) methods in Poisson regression found rain pools being the most productive habitat type compared to tyre tracks. However, unlike in the first larval model where hoof prints were

the least productive habitat type, in this model, they were as productive as the burrow pits. Drainage canals were less productive compared to tyre tracks (Table 4).

Table 4: Testing statistical significances in larval production among different habitats using repeated measures Poisson regression analysis in GEE methods

Habitat type	Daily larval productivity per habitat	
	Estimate (RR) (95%CL)	P
Burrow pits	1.26 (0.76-2.10)	<0.0001
Drainage canals	0.80 (0.36-1.75)	0.0009
Hoof prints	1.24 (0.71-2.17)	<0.0001
Rain pools	1.63 (1.03-2.56)	<0.0001
Tyre tracks	1.00	-

RR= Relative risk

4.2.2 Pupal productivity

Burrow pits produced four times more pupae than all the other four types of habitats in absolute terms. Mean cumulative pupal production per habitat and per unit area showed that burrow pits produced three times the number of pupae produced by the other four habitat types combined (Table 5). Assuming mosquito pupal populations exhibit Poisson distribution, four different Poisson regression models were used to test differences in relative pupal production among the different habitat types. Tyre tracks were chosen as the reference group. In the first pupal model, using Poisson regression, statistical differences were tested in pupal production among habitat types with pupae as the dependent variable and habitat type as the explanatory variable. Hoof prints were not

included in any of the pupal models since no single pupa was collected from hoof prints and their inclusion in the models would have prevented convergence because of the large number of zeros.

Table 5: Total pupal production, mean cumulative larval production and daily larval production in 5 different habitat types during sampling period

Habitat type	Total pupal numbers	Mean cumulative pupal production per habitat (±95% CL)	Mean daily pupal production per unit (±95% CL)
Burrow pits	732	91.50 (227.60)	4.60 (8.03)
Rain pools	131	21.83 (41.48)	1.10 (1.42)
Tyre tracks	51	6.37 (15.21)	0.35 (0.5)
Drainage canals	18	3.60 (11.99)	0.18 (0.34)
Hoof prints	0	0 (0.00)	0 (0.00)
Total	932		

Results of Poisson regression analysis for this model indicated that burrow pits were the most productive relative to tyre tracks. Rain pools were also significantly more productive compared to tyre tracks while drainage canals were significantly less productive when compared to tyre tracks (Table 6). Overall, cumulative pupal productivity per habitat was significantly associated with the habitat type (Wald χ^2= 418.49, df=3, $p<0.0001$). The second pupal model was similar to the first except introducing an offset for area. Therefore, the second model tested differences in total pupal production per unit area. Similar results were obtained with pupal production per

unit area being significantly associated with habitat type (Wald χ^2= 383.06, df=3, p<0.0001) (Table 6).

Table 6: Testing statistical differences in cumulative pupae productivity among habitat types using Poisson regression analysis

Habitat type	Df	Cumulative Pupal productivity per habitat		Cumulative Pupal productivity per unit area	
		χ^2	P	χ^2	P
Burrow pits	1	246.77	<0.0001	219.03	<0.0001
Drainage canals	1	12.93	0.0003	8.84	0.0029
Rain pools	1	20.59	<0.0001	12.16	0.0005
Tyre tracks	0	-	-	-	-

Df= Degrees of freedom

On daily basis, burrow pits, produced three times as many mean pupae as the rest of the other habitat types combined. No single pupae was obtained from hoof prints for the entire period of 25 days. The third pupal model was similar to the first with addition of repeated measures to take care of correlation between different visits of the same habitat since sampling was being done on daily basis. Thus, repeated measures Poisson regression testing statistical differences in daily pupal productivity per habitat showed that burrow pits were 10 times more productive compared to tyre tracks (RR=9.64, P<0.0001). Rain pools were 2 times more productive compared to tyre tracks (RR=2.24, P<0.0001) while drainage canals were $^2/_3$ less productive than tyre tracks (RR=0.36, P=0.0003). Table 7 shows the risk ratios and P values of the GEE results of the third and fourth pupal model at 95% confidence intervals for habitat type. The final pupal model was similar to the third but with an offset for area. With area control, burrow pits were 9

times (RR=8.81, P<0.0001) more productive than tyre tracks while rain pools were 2 times (RR=1.68, P=0.0064) more productive than tyre tracks as was the case in the model without control for area. Drainage canals were $^{3}/_{5}$ less productive than tyre tracks (RR=0.39, P=0.0007) for pupal per unit area.

Table 7: Testing statistical differences in pupae production in different habitats using repeated measures Poisson regression analysis in GEE methods

Habitat type	Daily Pupal productivity per habitat		Daily Pupal productivity per unit area	
	Estimate (RR) (95%CL)	P	Estimate (RR) (95%CL)	P
Burrow pits	9.64 (2.73-34.09)	<0.0001	8.81 (2.57-30.19)	<0.0001
Drainage canals	0.36 (0.07-1.91)	0.0003	0.39 (0.08-1.92)	0.0007
Rain pools	2.24 (0.46-11.01)	<0.0001	1.68 (0.36-7.79)	0.0064
Tyre tracks	1.00	-	1.00	-

RR= Relative risk

4.2.3 Association between larval production and habitat stability

In this study, habitat stability was defined as the presence or absence of water in the habitat during the period of sampling. Stability is expressed as the number of days the habitat was wet in the 25 days of sampling. The least stable habitat was only wet during two visits and the most stable was wet for all 25 visits. The 34 habitats were found wet in 67% of the 841 observations made. Hoof prints were the least stable (78% unstable) while the rest of the other habitats types were present nearly 80% of the study time. Figure 4 shows overall habitat stability for the 25 days sampling was done.

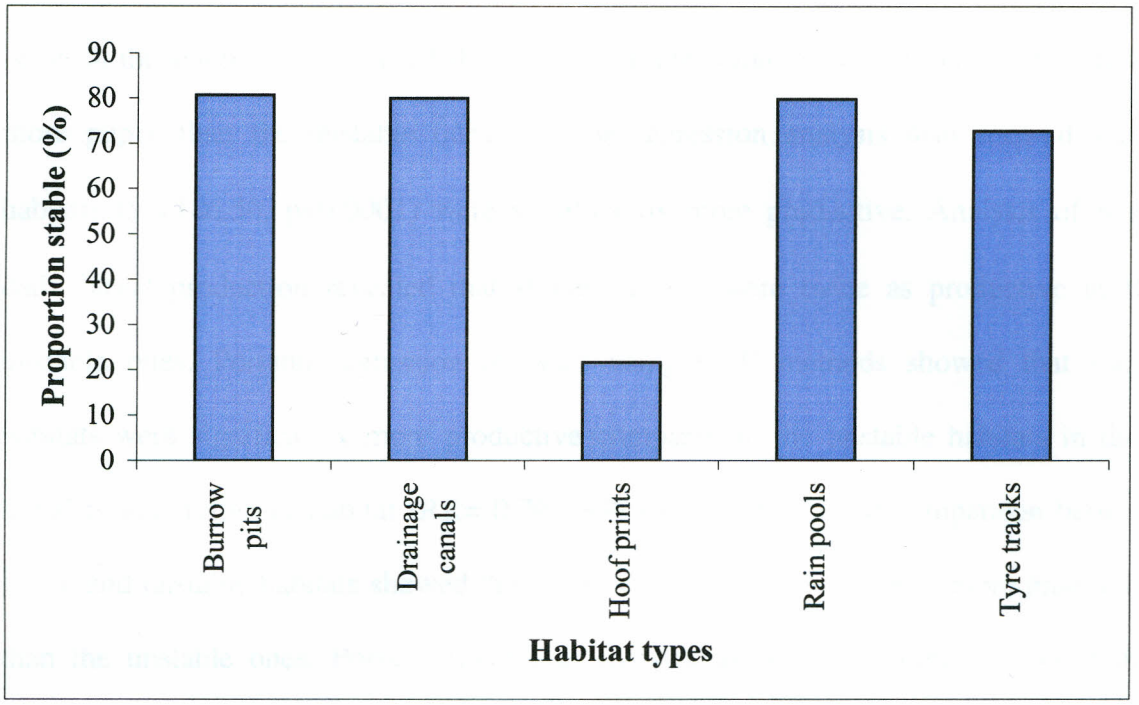

Figure 4: Habitat stability by habitat type in 25 days period

Habitats were categorized according to their state (dry or wet) at each visit, into stable habitats, that is those that were wet over 18 days and unstable habitats, those that were wet for 18 days or less. This categorization was arrived at after examining the number of days each habitat was wet. For most of the habitat types, half of them were wet for 18 days or less while the other half was wet for more than 18 days. In cumulative terms, comparison of mean stability of stable and unstable habitats showed that stable habitats produced twice the number of larvae produced by the unstable habitats during the entire sampling period. Poisson regression analysis using total larvae as dependent variable and habitat stability as explanatory variable showed that stable habitats were more productive than unstable habitats (χ^2=110.38, p<0.0001). Comparison of mean pupal production

between the stable and unstable habitats showed that stable habitats produced four times more pupae than the unstable ones. Poisson regression analysis also showed stable habitats (χ^2=186.50, p<0.0001) were significantly more productive. Analysis of mean daily larval production revealed that stable habitats were twice as productive as the unstable ones. Poisson regression analyses using GEE methods showed that stable habitats were significantly more productive compared to the unstable habitats in daily larval productivity per habitat (RR= 0.76, p<0.0001). Mean pupal comparison between stable and unstable habitats showed that stable habitats were four times more productive than the unstable ones. Poisson regression analysis using GEE methods showed that stable habitats were significantly more productive compared to the unstable habitats in both daily pupal productivity per habitat and per unit area (RR= 0.34, p<0.0001) and (RR= 0.52, p<0.0001) respectively.

4.2.4 Association between habitat productivity and habitat area

Habitat area ranged from 25 cm^2 to 360000 cm^2. It was categorized into small habitats (Area<=50000 cm^2) and large habitats (Area>50000 cm^2). This categorization, as in the case of habitat stability was arrived at after examining where half of all habitats in each category lie. Rain pools had the largest size with a mean area of 83650.67 cm^2 and hoof prints were the smallest with a mean area of 406.79 cm^2 (Table 8). Smaller habitats comprised 71% of all the habitats (Table 8). Habitat area measurements were done in 66.6% of the observations made, in the remaining observations these measurements were not taken because either the habitat was dry or flooded. A total of 560 length and width measurements were taken, 64% of these observations were made for smaller habitats.

Table 8: Habitat surface area by habitat types

Habitat type	Mean area (cm^2)	Percentage of habitats in a given area category	
		Area<=50000 (cm^2)	Area>50000 (cm^2)
Burrow pits	49308.11	62.50	37.50
Drainage canals	48088.6	60.00	40.00
Hoof prints	406.79	100.00	0.00
Rain pools	83650.67	33.33	66.67
Tyre tracks	34800.38	87.50	12.50
Total		**70.59**	**29.41**

Larger habitats produced twice the number of larvae and pupae produced by smaller ones in cumulative terms. Poisson regression analysis with total larvae as the dependent variable and habitat area as the explanatory variable, without control for area showed smaller habitats were significantly less productive (χ^2=66.52, p<0.0001) compared to larger habitats. Poisson regression model for pupae was done without control for area; the results obtained were similar to those of larval model where larger habitats produced more pupae (χ^2=10.66, p<0.0011) compared to smaller habitats. However, when same regression model was run with area as offset, smaller habitats produced equal number of pupae as larger ones (χ^2=117.13, p<0.0001). Mean daily larval productivity for smaller habitats (mean=8.76) were almost similar to those of larger habitats (mean=7.28). However, Poisson regression analysis showed that smaller habitats produced twice the number of larvae produced by larger habitats daily (RR=1.66, p<0.0001). Mean daily pupal productivity showed that larger habitats produced twice the number of pupae

produced by smaller habitats. However, Poisson regression analysis using the GEE methods without an offset for area showed small habitats produced almost the same number of pupae as the large habitats (RR=0.84, p<0.0052). When the same Poisson regression analysis was run with an offset for area, smaller habitats were three times more productive (RR=3.12, p<0.0001).

4.2.5 Association between habitat productivity and distance to the nearest house

Distance of the nearest house from the habitat was estimated for the 34 larval habitats sampled using the GIS equipment used for mapping them. The nearest house to a larval habitat was 0 metres while the furthest was 167 metres away and the average distance to the nearest house for the 34 habitats was 49.4 metres. As was the case with stability and habitat area, distance to the nearest house was categorized into close habitats (≤ 50m) and distant habitats (>50m). With this categorization, 22 habitats were close while 12 were distant habitats. Mean cumulative larval productivity for close habitats (mean=138.95) was almost similar to that of distant habitats (mean=128.83). Poisson regression analysis did not show any significant difference in cumulative larval production between the close and distant habitats (χ^2=1.07, p=0.3012). Close habitats were four times more productive when mean cumulative pupal productivity comparison was done. However, Poisson regression analysis without an offset for area did not show any significant difference in pupal production between close and distant habitats (χ^2=0.32, p=0.5724). With an offset for area, the same Poisson regression analysis showed that distant habitats were more productive than close ones though this different was not significant (χ^2=0.3.81, p=0.0508).

On daily basis, mean larval productivity for close habitats (mean=5.63) was almost similar to that of distant habitats (mean=5.18). Poisson regression analysis did not show any significant difference in daily larval production between the close and distant habitats (RR=0.90, p=0.1250). Mean pupal productivity showed that close habitats were four times more productive than distant habitats. Poisson regression analysis without an offset for area did not show any significant difference in pupal production between close and distant habitats (RR=1.12, p=0.4167). Similar results were obtained when the same Poisson regression analysis with an offset for area was run (RR=1.13, p=0.4883).

CHAPTER 5: DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 DISCUSSION

5.1.1 Identification and mapping of larval habitats

This study was part of a major project that was initiated in western Kenya to collect information on the distribution, abundance and productivity of *An. gambiae* s.l larval habitats that can be used to design source reduction interventions as a malaria control measure. Attempts were made to describe how *An. gambiae* s.l larval habitats are formed and to determine their productivity in a malaria endemic area of Kisumu District of Western Kenya. Previously, most larval ecology studies have been limited largely to descriptive work such as collection, sampling and of sampling data, with very limited experimentation, only alluding to a human factor in the creation of these habitats (Goma, 1966; Gillies and de Meillon, 1968; Gimnig *et al.,* 2001; Minakawa *et al.*, 2002b). None of the previous studies have measured mosquito production in the various habitats as well as gaining an in-depth understanding of the exact nature of the human contribution to habitat existence. The results of the study showed that mapping and identification survey of the larval habitats is essential because it gives an indication of the various types of larval habitats and which ones are likely to be more productive. As pointed out by Carter (2000), the number and productivity of larval habitats ultimately determines the density of the female *Anopheles* adult mosquitoes and therefore in attempting effective and cost-effective interventions, questions of location, environment and biology and behaviour of vector and host should not be disregarded. All the habitats identified as productive larval habitats for *An. gambiae* s.l were man-made except for rain pools and streambeds, which were naturally occurring. Farming, domestic water uses, animal husbandry, making mud

walls and transportation were inferred as the major reasons for the existence of larval habitats in this community. Among the habitat proliferating human activities, domestic water needs compared to farming and making of mud walls, were the major contributor to the existence of the habitats. In concurrence with the findings of Minakawa *et al.* (2002b) and Keating *et al.* (2003), this study demonstrated a strong human factor in the abundance of *An. gambiae* s.l larval habitats, with more than 80% of the habitats identified and mapped being manmade. This observation suggests that control of this vector will require understanding habitat creation related human behaviour in order to come up with effective community participation in vector control strategies.

This study presumes that the reason why mainstream larval control activities have not had much success relates to failure to take cognizance of the relationship between most habitat proliferating activities and the livelihoods of rural communities. This is because classical mosquito control methods advocate environmental management involving land, water, and physical characteristics as the most effective and permanent methods to reduce the breeding places. These include such source reduction methods as draining, filling, ditching, flushing, and water management as well as larval control using bio-insecticides (Minakawa *et al.*, 2002b; Najera and Zaim, 2002). However, this approach has been devoid of the human behaviour aspect that makes people create the larval habitats. The results suggest that decisions aimed at taking actions for preventing habitat creation or mosquitoes breeding have to take in consideration the human habitat uses. A dilemma of conflict in domestic needs of water in the habitats versus public health needs could however be a possible impediment in controlling mosquito breeding in this community. It can thus be inferred that larval habitats of *An. gambiae* s.l. can be

located and mapped relative to land use, and their origin relative to anthropogenic activity determined. When the actual quantity of productive larval habitats is known it is easier to design specific intervention measures. This documenting of the characteristics and hydrological features of the productive larval habitats could be an important tool for communities in malaria endemic areas.

5.1.2 Mosquito productivity

As stated by Goma (1958), the results from this study demonstrated that, it is possible to determine mosquito productivity of the various types of larval habitats. Differences in larval densities were noted within the habitat types and between cumulative and daily larval densities. Rain pools followed by burrow pits had the highest larval densities both in terms of cumulative and daily larval density. Hoof prints were the least productive in cumulative terms, but as productive as burrow pits on daily basis. Given that hoof prints were the least stable; these results indicate that the differences in larval density when cumulative and daily larval densities were compared were as a result of habitat stability. An observation, which the results of the present study could not explain, was the differences in larval densities in habitats within the same habitat type. On the other hand, burrow pits were by far the most productive habitat type in terms of the pupae (adult mosquitoes). Despite being commonly occupied by larvae and contrarily to classical knowledge that hoof prints are good sources of the malaria vector, *An.gambiae* s.l, no single vector was obtained from them. The inability of the hoof prints to produce vectors could be explained by their highly unstable nature either due to their small size or due to disturbances such as flooding and flushing off. There were no significant differences

between cumulative and daily productivity of adult mosquitoes may be because all the habitat types included in models comparing adult mosquito productivity had almost similar stability unlike in case of larval densities where hoof prints were by far very unstable relative to other habitat types.

Habitats grouped under same habitat type in this study had similar characteristics such as form, hydrology, use, stability and size. However, it was noted that within a particular habitat type some habitats were more productive than others, while others did not produce a single adult. This requires more research to establish why these habitats do not support larvae to adults despite having similar characteristics with others that are good sources of the vectors. Habitat form (type) comes out clearly in this study as important factor in adult mosquito productivity. The form attained by burrow pits was shown as an appropriate form for mosquito production while that attained by drainage canals was least appropriate. A number of reasons could be attributed to the differences in mosquito productivity in the different habitat forms. One of these reasons could be hydrology, which is how the water enters into the habitat and the geography surrounding the habitat. Is habitat able to withstand flooding in case of heavy rains? Rain pools though the largest habitats and also having the highest larval density were frequently flooded because of their form. Hoof prints were also easily flooded and dried up quickly. None of the burrow pits was ever flooded during the sampling duration. A second reason contributing to the differences in mosquito productivity among the habitat types could be the habitat use. Burrow pits were the most used habitats. Together with drainage canals, burrow pits were mainly used for domestic use and as watering points for cattle. While rain pools and tyre tracks were mainly used for watering cattle. Perhaps the effect of

habitat use was more evident in rain pools and tyre tracks, where despite having high densities of larvae very few proceeded to pupae. Disturbance caused by humans and animals while using the habitat may lead to larvae and pupae mortality.

The stability of habitat is determined by whether it will maintain water for gravid female mosquitoes to oviposit, sustain the larval instars to successfully develop into adult mosquitoes. Hoof prints, the least stable habitats, could not last long enough to allow even a single cohort of larvae to reach the pupal stage, while burrow pits were the most productive habitat type and also the most stable. In the study area, hoof prints cannot be termed as foci of malaria transmission since no single adult was obtained from them during the study period, a period long enough to allow development of two cohorts of mosquitoes from egg stage to adults. Habitat stability seemed to depend on habitat hydrology, size and use. All burrow pits in this study were created through human influence either to preserve water for various uses in the community or to scoop soil for making mud walls. The form attained by burrow pits, because of these actions is the one that allows retention of water relatively long enough for mosquito production. Rain pools, the only naturally occurring habitat type, in the study area and drainage canals though stable were not good sources of the vector. Mosquito larvae predators have been shown to play an important role in regulating vector populations (Mogi, 1993). As noted by Service (1973) other than the effect of habitat uses, successful development of the immatures up to adult stage in rain pools and drainage canals could also have been hampered by the presence of predators because when the habitat is stable, there is a possibility of predators colonizing it. Overall, it was shown in this study that habitat

stability was an important factor in mosquito production with the stable habitats being more productive.

Distance of the nearest house from a habitat did not seem to affect larval density within the study area. This may be explained by the fact that all the habitats sampled were within the flight range of the *Anopheles* malaria vectors in most African settings, which is generally less than 1km (Charlwood *et al.*, 1998 and Takken *et al.,* 1998) moreover, almost all the habitats sampled in this study were typical *An. gambiae* s.l larval habitats which have anthropogenic origin and thus found very close to human habitations. On the other hand, though the results did not show this explicitly and in agreement with findings of Minakawa (1999), there were indications that those habitats close to the houses ($\leq$ 50m) produced more adults than those that were distant from the houses (> 50m). Since there are no significant differences in larval densities between the close and distant habitats, it means there was higher larval mortality in the distant habitats than in the close ones. This presents a challenge for future research to explain factors behind the differences in adult mosquito productivity between close and distant habitats.

5.2 CONCLUSIONS

a) Larval habitats of *An. gambiae* s.l. can be located and mapped relative to land use, and their origin relative to anthropogenic activity determined.

b) Human activities contribute significantly in the creation of *An. gambiae* s.l larval habitats calling for a clear understanding of the human activities in malaria endemic areas so as to formulate larval control interventions that are acceptable to the community and sustainable.

c) Mosquito production differs in the different larval habitat types either because of the habitat form or stability or size or use

5.3 RECOMMENDATIONS

a) In addition to doing more studies to quantify the effects of habitat stability, habitat size and proximity of habitats to host, more studies should be done on the effects of chemical or microbial content of water in larval habitats and predators among other factors on mosquito larval habitat productivity.

b) More research is also required to find ways of creating a conducive environment for active community participation in larval control that is evidence based.

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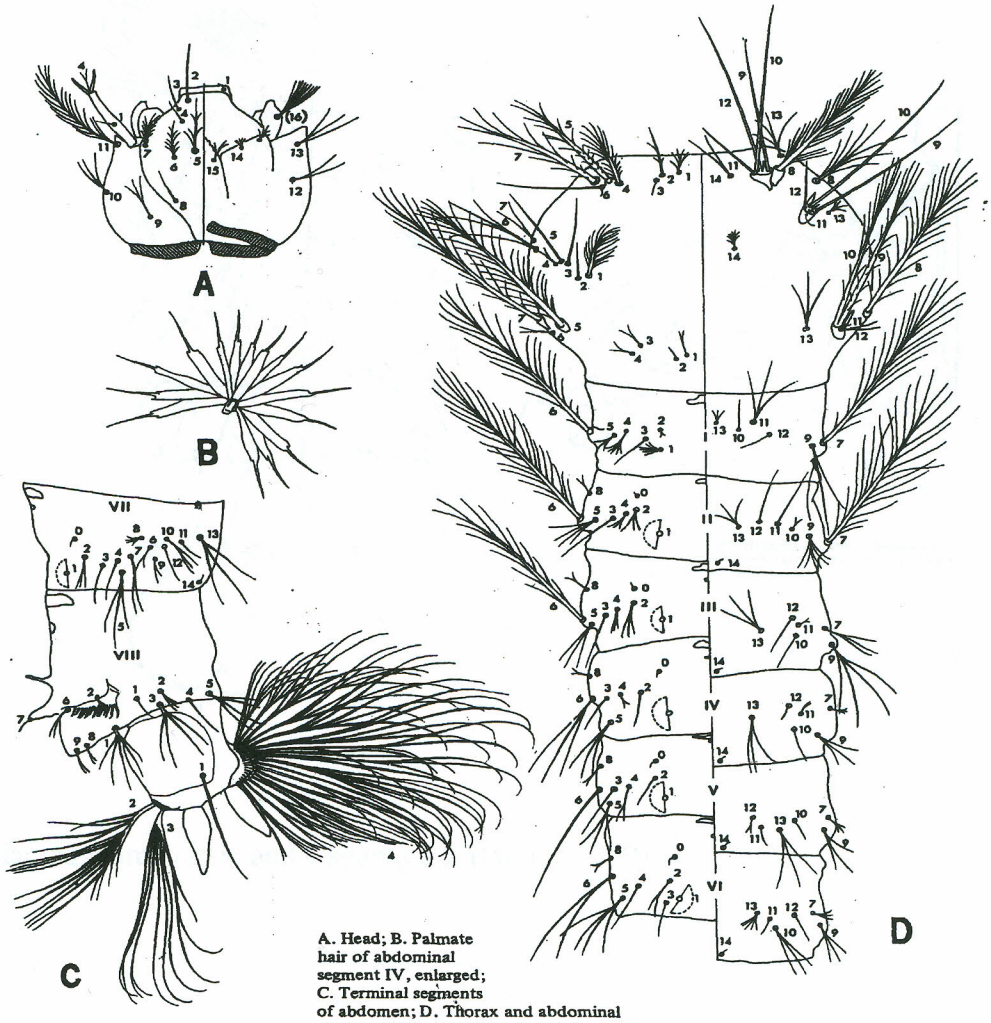
LIST OF APPENDICES

APENDIX I: IDENTIFICATION OF ANOPHELES LARVAE

Fourth instar larva of *Anopheles* Litoralis king, showing chaetotaxy

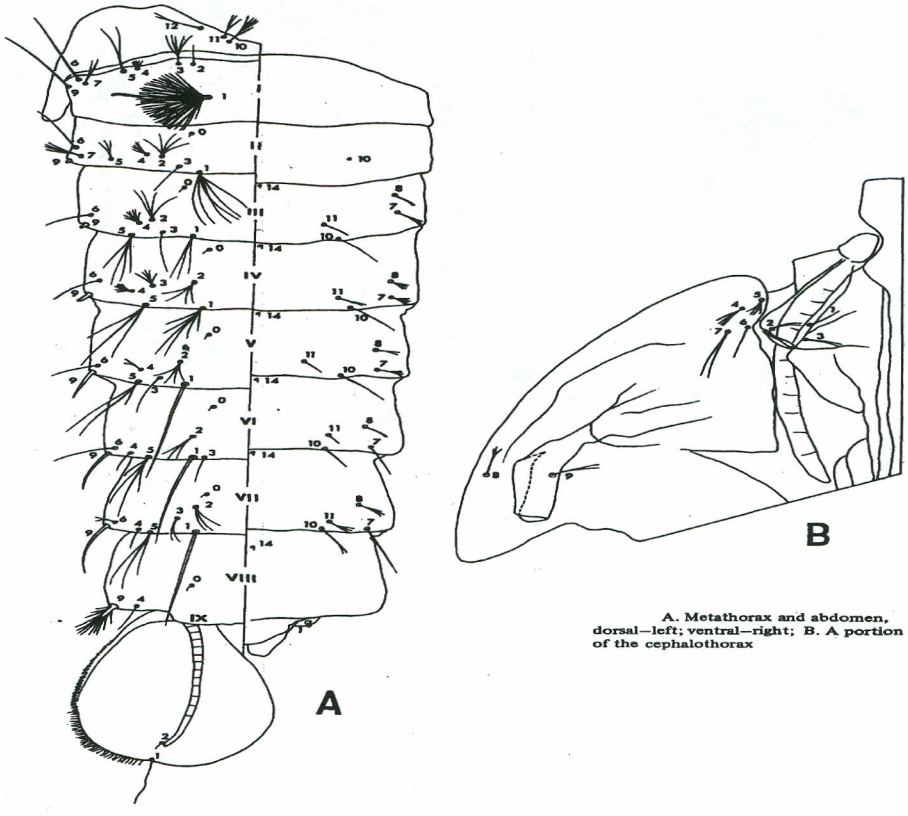


A. Head; B. Palmate hair of abdominal segment IV, enlarged; C. Terminal segments of abdomen; D. Thorax and abdominal segments I-VI, dorsal—left, ventral—right.

(Adapted from Darsie and Cagampang-Ramos, 1969)

APENDIX II: IDENTIFICATION OF ANOPHELES PUPA

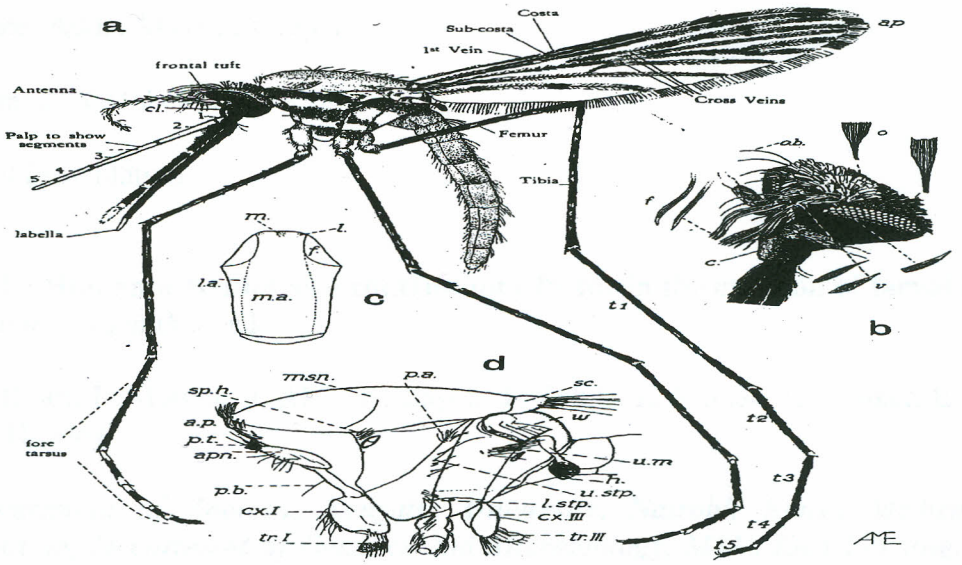
Pupa of *Anopheles* Litoralis king, showing chaetotaxy



A. Metathorax and abdomen, dorsal—left; ventral—right; B. A portion of the cephalothorax

(Adapted from Darsie and Cagampang-Ramos, 1969)

APENDIX III: IDENTIFICATION OF ANOPHELES ADULT



FEMALE *Anopheles* (after Evans, 1938). **a**-Whole insect in side view, showing main parts of body; one palp raised and denuded of scales to show segments. t1-t5 the five segments of the hind tarsus, *ap.* Wing-apex, *cl.* Clypeus. **b**-Head seen obliquely to show scaling; individual scales from occiput *(o)*, vertex *(v)*, and frontal tuft *(f)* enlarged to show average shape. *c.* clypleus, *o.b.* orbital bristles. **c**-Upper surface of thorax. m.*a.* median area, *l.a.* lateral area, *f.* fossa, *m.* median and *l.* lateral positions on anterior promontory where scales are commonly attached. **d**-Side thorax; *a.p.* anterior promontory, *apn.* anterior pronotal nobe, *cx.I* fore coax, *cx.III* hind coax, *h.* haltere, *l.stp.* lower sternopleural or mesepisternal bristles, *p.a.* prealar tuft of bristles, *p.b.* Propleural bristle, *p.t* pronotal scale tuft, *sp.h.* spiracular hairs or bristles, *tr.I* fore trochanter, *tr.III* hind trochanter, *u.stp.* upper sternopleural or mesepisternal bristles, *u.m.* upper mesepimeral bristles, *w.* base wing.

APPENDIX VIII: ARTICLE PRESENTED

Name: 24th Africa Health Sciences Congress

Place: Addis Ababa, Ethiopia

Date: 2nd October 2003

Oral Presentation

Title: Human activities as a contributory factor in the creation of larval habitats for *Anopheles gambiae* s.l

Authors: F. Mutuku, J. Alaii, N. Bayoh, J. Vulule, L. Kamau, E. Walker, E. Kabiru, and W. Hawley.

Department of Zoology, Kenyatta University, Nairobi; Kenya Medical Research Institute; Department of Genetics and Microbiology, MSU, East Lansing, Michigan,; Division of Parasitic Diseases, NCID, CDC, Atlanta, Georgia.

Abstract

Introduction: A study of mosquito larval habitats to ascertain their productivity in a low-lying malarious area of western Kenya. Observational studies suggested a human link in the existence of almost all larval habitats for *An. gambiae*. *Rationale and objective*: The importance of human behaviour in the proliferation of larval habitats of malaria mosquitoes is largely overlooked. The study aimed to determine the impact of human activities on *An. gambiae* productivity in the study area, and the implications for designing interventions targeting reduction of mosquito breeding. *Methods*: All potential larval habitats within the study area were investigated to determine habitat abundance, stability and productivity and whether they were created naturally or by human activity. Qualitative studies including observations, focus group discussions (FGD), and In-depth interviews were used to document information on human activities that lead to habitat creation, the usefulness of the habitats to the community, and the implications of habitat reduction and larval control. *Results*: The most productive habitat types were burrow pits, drainage canals, tyre tracks, hoof prints, rain pools and streambeds. With the exception of rain pools and streambeds, all of the productive habitats were created by human activity. Participants in FGD and In-depth interviews portrayed knowledge of malaria aetiology. While they appeared to link the existence of mosquito vectors to the presence of habitats, they portrayed lack of knowledge of the exact identity of the mosquito stages present in the habitats. Although there was an awareness of the contribution of the habitats to mosquito production and malaria, there was a general reluctance in the control of the proliferation of habitats because of their utility in domestic and farming activities. *Conclusions*: The implications for health intervention design to target appropriate social and behavioral changes for mosquito larval habitat control are discussed.

APPENDIX V: POSTER PRESENTED

Name: 52nd American Society of Tropical Medicine and Hygiene

Place: Philadelphia, USA.

Date: 6th December 2003

Poster Presentation

Title: Habitat production for A*nopheles gambiae* larvae and pupae: Relationship to habitat hydrology, form, and stability

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Department of Zoology, Kenyatta University, Nairobi, Kenya, Kenya Medical Research Institute, Kenya,* Department of Microbiology and molecular genetics, MSU, East Lansing, Michigan, MI; *Division of Parasitic Diseases, NCID, CDC, Atlanta, Georgia

Abstract:
The production of An. gambiae s.l pupae from larval habitats is the primary determinant of adult density of this important malaria vector within endemic communities. However, estimates of production and its variation in time and space have not been carefully quantified. We surveyed a village in western Kenya for larval habitats, mapped them with geopositioning equipment, and selected a subset of them (34) for daily, longitudinal sampling using maximum density area sampling and census methods, during a period of 25-days in the short rainy season. All the different types of An. gambiae s.l habitats present in the study area were represented in the subset. Results showed variations in overall production, with soil burrow pits near dwellings and rain pools being the most productive; while cattle hoof prints, although commonly occupied by larvae, did not produce any single pupa during the entire study. Larval populations were dynamic as a function of rainfall and corresponding habitat area, depth, and stability. Habitat persistence strongly affected overall production.