

Mosquito species diversity and abundance in relation to land use in a riceland agroecosystem in Mwea, Kenya

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ABSTRACT: We conducted an entomological survey to determine the mosquito species diversity and abundance in relation to land use in the Mwea rice scheme, Kenya. Adult mosquitoes were collected by indoor spraying of houses and outdoors by CDC light traps in three villages representing planned (Mbuinjeru) and unplanned (Kiamachiri) rice agroecosystems and a non-irrigated agroecosystem (Murinduko). During the 12-month sampling period, a total of 98,708 mosquitoes belonging to five genera and 25 species were collected. The five most common species collected during this study were *Anopheles arabiensis* Patton (52.5%), *Culex quinquefasciatus* Say (36.7%), *Anopheles pharoensis* Theobald (5.2%), *Anopheles coustani* Laveran (1.4%), and *Anopheles funestus* Giles (1.3%). *Anopheles arabiensis*, *Cx quinquefasciatus*, and *An. pharoensis* were more abundant in rice agroecosystems than in the non-irrigated agroecosystem, and in planned than in the unplanned rice agroecosystems. In contrast, *An. funestus* was more abundant in the non-irrigated agroecosystem. The mosquito species diversity (H) and evenness (E_H) in the non-irrigated agroecosystem (Shannon diversity Index, $H = 1.507$, $E_H = 0.503$) was significantly higher than in the rice agroecosystems ($H = 0.968$, $E_H = 0.313$, unplanned; and $H = 1.040$, $E_H = 0.367$ planned). Results of lag cross correlation analysis revealed a strong relationship between rainfall and the abundance of *An. arabiensis*, and *C. quinquefasciatus* in the non-irrigated agroecosystem but not in the rice agroecosystems. It is inferred from the data that different levels of habitat perturbations with regard to rice cultivation have different effects on mosquito diversity and abundance. This provides an understanding of how mosquito diversity is impacted by different habitat management and rice cropping strategies. *Journal of Vector Ecology* 31 (1): 129-137. 2006.

Keyword Index: *Anopheles arabiensis*, *Culex quinquefasciatus*, planned and unplanned rice cultivation, agroecosystem.

INTRODUCTION

Irrigated rice agroecosystems in Africa are associated with a wide spectrum of mosquito fauna. In a study to investigate the succession of mosquito species and their abundance in relation to rice cropping cycles in Bansang, Gambia, 32 mosquito species from seven genera were observed (Snow 1983). In Lower Moshi Tanzania, ten species belonging to the genera *Anopheles*, *Culex*, and *Mansonia* co-existed in a rice-village complex (Ijumba et al. 2002). In the Kano Plains, Kenya, indoor and outdoor adult mosquito collections in a rice agroecosystem yielded a total of 35 species from eight genera (Surtees et al. 1970, Chandler et al. 1975, Chandler et al. 1976). More recently, the population of pre-adult stages of anopheline and culicine mosquitoes was reported to increase after application of ammonium sulphate in Mwea rice fields, Kenya (Mutero et al. 2004a). However, despite the importance of rice cultivation in the proliferation of diverse mosquito species, most research efforts in African rice agroecosystems have been directed towards *Anopheles gambiae* s.l. Giles and *Anopheles funestus* Giles (Chandler et al. 1976, Marrama et al. 1995, Ijumba et al. 1990, 2002, Ijumba and Lindsay 2001, Briet et al. 2003, Klinkenberg et al. 2003, Mutero et al. 2000, 2004a, 2004b).

Studies across Africa have demonstrated the link between irrigated agriculture and health. Although irrigation may not necessarily increase the prevalence of malaria (Ijumba and Lindsay 2001, Mutero et al. 2004b), it has been shown to aggravate the problem of other mosquito-borne diseases. A study by Hunter et al. (1992) in northeast Ghana revealed that all communities reporting Bancroftian filariasis as a public health problem were former beneficiaries of irrigated agricultural development. In the Gomoa Okyereko rice agroecosystem in Ghana, natural infections of Bancroftian filariasis were reported in *Culex quinquefasciatus* and *Mansonia* species (Mawuli et al. 1999). An increase in soil moisture associated with irrigation development in the southern Nile Delta, following the construction of the Aswan High Dam, caused a rapid rise in the abundance of *Cx quinquefasciatus* Say, and consequently, an increase in prevalence of Bancroftian filariasis (Thompson et al. 1996). Also in the Nile Delta, *Cx. quinquefasciatus* females were 3.3 times more likely to be infected in agriculturally-based villages than non-agricultural rural villages (Farid et al. 2000). A 12-month field and laboratory study in the Igwu agro-Basin, Nigeria, found all clinical signs associated with microfilariiae to be attributed to *An. gambiae* s.l. and *Cx quinquefasciatus* with mean infection rates of 21.7% for *An.*

gambiae s.l. and 22.7% for *C. quinquefasciatus* (Udonsi 1988). Along the Senegal River Basin, *Cx. Poicilipes* Theobald was incriminated as a new vector of Rift Valley Fever virus (RVF) and was inferred to have been involved in 1998-1999 RVF outbreaks in the area (Diallo et al. 2000). An isolate of West Nile Virus (WNV) was obtained from a pool of four male *Cx. univittatus* Theobald mosquitoes while conducting an investigation of Rift Valley Fever virus in the Turkwel Gorge Hydroelectric Project within an irrigational compound along the Kenya-Uganda border (Miller et al. 2000). Additionally, mosquitoes cause considerable biting annoyance and interfere with both indoor and outdoor activities particularly in irrigated agroecosystems where they occur in abundance (Lacey and Lacey 1990). Understanding the biodiversity and distribution of mosquitoes in man-made water and irrigation projects is therefore highly desirable.

A proper understanding of the relationship between agricultural activity and the occurrence, abundance, and distribution of mosquito densities may provide information relevant to the development and implementation of an Integrated Vector Management (IVM) program based on adult productivity and variability. In order to evaluate the relationship between farming practices and mosquito species diversity, we conducted a preliminary entomological study in three villages representing different agroecosystems. Our principal objective was to provide updated information on the diverse mosquito fauna associated with rice cultivation in Mwea, Kenya, prior to implementation of a malaria vector control program.

MATERIALS AND METHODS

Study sites

The study was conducted in Mwea division in Kirinyaga District, 100 km northeast of Nairobi. The study area has been described previously (Mutero et al. 2004a, 2004b). Mwea rice scheme occupies the lower altitude zone of Kirinyaga District in an expansive low-lying area characterized by black cotton soil. The annual rainfall varies from a maximum of 1,626 mm to a minimum of 356 mm, with an average of 950 mm per year. The average temperatures are 21.3° C (range: 16.0 to 26.5° C) and the relative humidity averages 59.5% (range: 52 to 67%). According to the 1999 national census, Mwea division has an estimated 150,000 persons in 25,000 households. The Mwea Irrigation Scheme is located in the west-central region of Mwea division and covers an area of about 13,640 ha. Over 50% of the scheme area is used for irrigated rice cultivation while the remaining area is used for subsistence farming, grazing, and community activities. Three villages, namely Mbuinjeru, Kiamaciri and Murinduko, were selected for the study based on rice cultivation practices and the extent of rice coverage within a radius of 1 km from the village perimeter.

Mbuinjeru is within the Mwea irrigation scheme (MIS) and over 75% of the village land is under rice cultivation. Farmers in this village follow a definite rice cropping cycle as determined by the National Irrigation Board (planned rice cultivation). The typical rice cultivation cycle includes a land

preparation–transplanting period (July–August), a growing period (August–November), and a post-harvest period (November–December). The second crop, if planted, is cultivated prior to the long rain period between January and May. Human habitation occupies the remaining area with less than 10% utilized for vegetables and bananas.

Kiamaciri is immediately outside the scheme and approximately 20% of the area is under rice cultivation. In this village, individual farmers decide their own cropping cycle depending on water availability. Consequently, rice is grown throughout the year as long as water is available in the Gakungu River that feeds the rice paddies (unplanned rice cultivation). The time of planting varies from farmer to farmer and it is therefore common practice to find rice in different stages of development all year. The remaining 80% of the land is mainly under maize, beans, and bananas.

Murinduko is at the periphery of the scheme approximately 15 km from Mbuinjeru with no rice cultivation or any form of irrigation (non-irrigated village). Maize, beans, and bananas are the main crops cultivated but only on subsistence scale in an area approximately 70% of the village.

Meteorological data

A rain gauge (Tru-Chek®, Rain Gauge Division, Edwards Manufacturing Co. Albert Lea, MN, U.S.A.) was placed in each of the three villages and rainfall data recorded daily over a period of 12 months (April 2004 to March 2005). Temperature and relative humidity for each village was also taken using temperature and relative humidity data loggers (Onset Computer Corporation, Bourne, MA, U.S.A.).

Mosquito sampling

Adult mosquitoes were sampled fortnightly in 30 randomly selected houses in each of the three villages between April 2004 and March 2005. The same houses were sampled throughout the study period but on some occasions circumstances required that a nearby house be substituted. The houses were sampled in the morning (07:00-11:00 h) to collect indoor resting mosquitoes using the pyrethrum spray collection (PSC) method (World Health Organization 1975). White sheets were spread on the floor of the whole house and the house sprayed with 0.3% pyrethrum in water. All knocked-down mosquitoes were collected in Petri dishes and transported to the laboratory for identification. Concurrent with PSC, six CDC light traps (J.W. Hock Ltd, Gainesville, FL, U.S.A.) were run outdoors fortnightly for two consecutive nights in each village between 18:00-07:00 h. The traps were distributed equally in three different locations of the village namely center, periphery, and 200 m away from the village periphery. The mosquitoes were subsequently identified morphologically to species (Edwards 1941, Gillett 1972). During the sampling period, the diverse larval habitat types present in each village were recorded.

Statistical analysis

Data were analyzed using SPSS version 11.5 statistical package (SPSS, Inc., Chicago, IL). Variation in adult mosquito densities between villages and months was compared using

analysis of variance (ANOVA) while the relationship between adult mosquito density and rainfall was analyzed using cross correlation analysis with different time lags.

Shannon diversity index (H) was used to characterize species diversity in the three study sites in Mwea. Shannon's index accounts for both abundance and evenness of the species present. The proportion of species i relative to the total number of species (p_i) is calculated and then multiplied by the natural logarithm of this proportion ($\ln p_i$). The resulting product is summed across species and multiplied by -1 (Magurran 1988, Rosenweig 1995).

$$H = -\sum_{i=1}^S P_i \ln P_i$$

Shannon's equitability (E_H) can be calculated by dividing H by H_{\max} (where $H_{\max} = \ln S$, the total number of species in the community (richness)). Equitability assumes a value between 0 and 1 with 1 being complete evenness.

RESULTS

Meteorology

The total precipitation for the period April 2004 to March 2005 was 810.4 mm, 679.8 mm, and 803.1 mm for the planned, unplanned, and non-irrigated agroecosystems, respectively. The rainfall pattern was typically bimodal with peak precipitation recorded in April and November (Figure 1). The number of rainy days was variable among planned (75 days; range: 1 – 11), unplanned (57 days; range: 1 – 17), and non-rice (76 days, range: 1 – 20) agroecosystems. In this period, the average daily temperature was 22.9° C (range 20.1 - 25.5° C) while the average relative humidity was 71.02% (range 56.6 - 83.4%).

Species composition and abundance

The relative abundance of mosquitoes collected by the two trapping methods in the three agroecosystems is shown in Table 1. A total of 98,708 mosquitoes belonging to five genera and 25 species was caught over the one-year period. The genus *Aedes* was more diverse with nine species, followed by *Anopheles* with eight species, *Culex* with five species, *Coquilletidia* with two species and *Mansonia* with one species. Among the anophelines, *An. arabiensis* was the predominant mosquito species (51,850) in all samples followed by *An. pharoensis* (5,165), which was mainly collected outdoors in the planned rice village. Other anophelines collected included *An. coustani* Laveran (1,335), *An. funestus* (1,264), *An. maculipalpis* Giles (555), *An. pretoriensis* Theobald (72), *An. rufipes* Gough (48), and *An. moucheti* Theobald (1). The genus *Culex* was mainly dominated by *Culex quinquefasciatus* (36,240). Other *Culex* species comprised 911 *Cx. annulioris* Theobald, 601 *Cx. poicilipes*, 44 *Cx. tigripes* Grandpre and Charmoy, and 82 other specimens which were indeterminate. The 472 aedine specimens collected yielded a total of nine species mainly dominated by *Aedes cummingsi* Theobald (276) and *Ae. taylori* Edwards (138). Other species captured were *Mansonia uniformis* Theobald (40), *Coquilletidia maculipennis* Theobald (18), and *Cq. fuscopennata* Theobald

(10).

Species diversity and evenness

The Shannon diversity index (H) was used to characterize species diversity in the three agroecosystems in Mwea, Kenya. The diversity (H) and evenness (E_H) of mosquito species in the non-irrigated agroecosystem (Shannon diversity Index, $H = 1.507$, $E_H = 0.503$) were much higher than in the sites with rice cultivation ($H = 0.968$, $E_H = 0.313$, Kiamaciri and $H = 1.040$, $E_H = 0.367$, Mbuinjuru). This implies that the non-irrigated agroecosystem had a greater number of species present with the individuals in the community being distributed more equitably among these species (Table 2).

Spatial distribution of mosquitoes

The mean number of mosquitoes captured in the planned rice agroecosystem was 3.2-fold higher than in the unplanned rice agroecosystem and 6.2-fold higher than in the non-irrigated agroecosystem. Significantly higher densities of *An. arabiensis* were collected in the planned rice agroecosystem both indoor and outdoor than in either of the other agroecosystems (ANOVA, $F=78.160$, $df_{2, 148}$, $P=0.000$). Comparing the unplanned rice agroecosystem and non-irrigated agroecosystem, similar densities of *An. arabiensis* were obtained in outdoor collections, whereas higher densities were captured indoors in the unplanned rice agroecosystem than in the non-irrigated agroecosystem. In contrast, indoor collected *An. funestus* were significantly higher in the non-irrigated agroecosystem than in the other agroecosystems (ANOVA, $F=104.01$, $df_{2, 290}$, $P=0.000$), whereas outdoors there was no site-to-site variation. Other anophelines with site-to-site variation included; *An. pharoensis* mainly occurring in the planned rice agroecosystem, *An. maculipalpis* mainly captured in the non-irrigated agroecosystem, and *An. coustani* whose density was lower in the unplanned rice agroecosystem than in the other agroecosystems. Among culicines, *C. quinquefasciatus* was the only species showing significant differences in densities between the three villages. Indoors, lower densities of *Cx. quinquefasciatus* were collected in the non-irrigated agroecosystem than in the other villages, whereas outdoors, the planned rice agroecosystem had significantly higher densities than the other agroecosystems. *Aedes cummingsi* (60.5%) and *Ae. taylori* (30.3%) were the most predominant species among the aedine mosquitoes collected. A higher density of *Ae. cummingsi* was recorded in the planned rice agroecosystem than in the other agroecosystems. No significant difference in densities of *Ae. taylori* was apparent among the three agroecosystems. Overall, only low densities of the other aedine mosquitoes were collected (Table 1).

Temporal distribution of mosquitoes

There was a significant monthly variation in the density of the three most common species namely *An. arabiensis*, *An. pharoensis*, and *Cx. quinquefasciatus* (ANOVA, $p<0.001$). The density of *An. arabiensis* was significantly correlated with rainfall in the non-irrigated agroecosystem but not in rice agroecosystems (Figure 1). Similar findings were observed for *Cx. quinquefasciatus*, whereas *An.*

Table 1. Relative abundance of mosquito species collected in the three agroecosystems in Mwea, April 2004-March 2005.

Mosquito species	Planned rice cropping village		Unplanned rice cropping village		Non-irrigated village	
	Light trap (%)	PSC (%)	Light trap (%)	PSC	Light trap	PSC
<i>Anopheles coustani</i>	591 (1.6)	0 (0)	248 (4.1)	0 (0)	472 (6.1)	24 (0.8)
<i>Anopheles funestus</i>	107 (0.3)	87 (0.3)	20 (0.3)	92 (0.6)	398 (5.2)	560 (18.0)
<i>Anopheles arabiensis</i>	8,809 (24.2)	26,399 (86.8)	1,367 (22.4)	10,983 (73.4)	2,846 (37.0)	1,446 (46.5)
<i>Anopheles maculipalpis</i>	0 (0)	0 (0)	46 (0.8)	0	501 (6.5)	8 (0.3)
<i>Anopheles moucheti</i>	0 (0)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)
<i>Anopheles pharoensis</i>	5,115 (14.1)	7 (0)	23 (0.4)	0 (0)	20 (0.3)	0 (0)
<i>Anopheles pretoriensis</i>	1 (0)	0 (0)	4 (0.1)	0 (0)	66 (0.9)	1 (0)
<i>Anopheles rufipes</i>	3 (0)	0 (0)	7 (0.1)	0 (0)	36 (0.5)	2 (0.1)
<i>Aedes aegypti</i>	0 (0)	0 (0)	1 (0)	0 (0)	11 (0.1)	0 (0)
<i>Aedes africanus</i>	0 (0)	0 (0)	0 (0)	0 (0)	7 (0.1)	0 (0)
<i>Aedes circumluteolus</i>	14 (0)	0 (0)	2 (0)	0 (0)	0 (0)	0 (0)
<i>Aedes cummingsi</i>	133 (0.4)	15 (0)	70 (1.1)	3 (0)	32 (0.4)	23 (0.7)
<i>Aedes haworth</i>	0 (0)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)
<i>Aedes longipalpis</i>	0 (0)	0 (0)	2 (0)	0 (0)	0 (0)	0 (0)
<i>Aedes taylori</i>	42 (0.1)	1 (0)	49 (0.8)	1 (0)	44 (0.6)	1 (0)
<i>Aedes vittatus</i>	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	0 (0)
<i>Aedes woodi</i>	3 (0.0)	0 (0)	0 (0)	0 (0)	16 (0.2)	0 (0)
<i>Culex annulioris</i>	231 (0.6)	9 (0)	391 (6.4)	16 (0.1)	262 (3.4)	2 (0.1)
<i>Culex poecilipes</i>	405 (1.1)	0 (0)	144 (2.4)	7 (0)	45 (0.6)	0 (0)
<i>Culex quinquefasciatus</i>	20,888 (57.4)	3,913 (12.9)	3,629 (59.4)	3,866 (25.8)	2,920 (37.9)	1,024 (33.0)
<i>Culex tigripes</i>	15 (0.04)	0 (0)	23 (0.4)	0 (0)	4 (0.1)	2 (0.1)
<i>Culex spp*</i>	29 (0.1)	0 (0)	35 (0.6)	0 (0)	5 (0.1)	13 (0.4)
<i>Coquilletidia fuscopennata</i>	0 (0)	0 (0)	9 (0.1)	0 (0)	1 (0)	0 (0)
<i>Coquilletidia maculipennis</i>	2 (0.01)	0 (0)	16 (0.3)	0 (0)	0 (0)	0 (0)
<i>Mansonia africana</i>	9 (0.02)	0 (0)	18 (0.3)	0 (0)	12 (0.2)	1 (0)
Overall Total	36,397	30,431	6,106	14,968	7,699	3,107

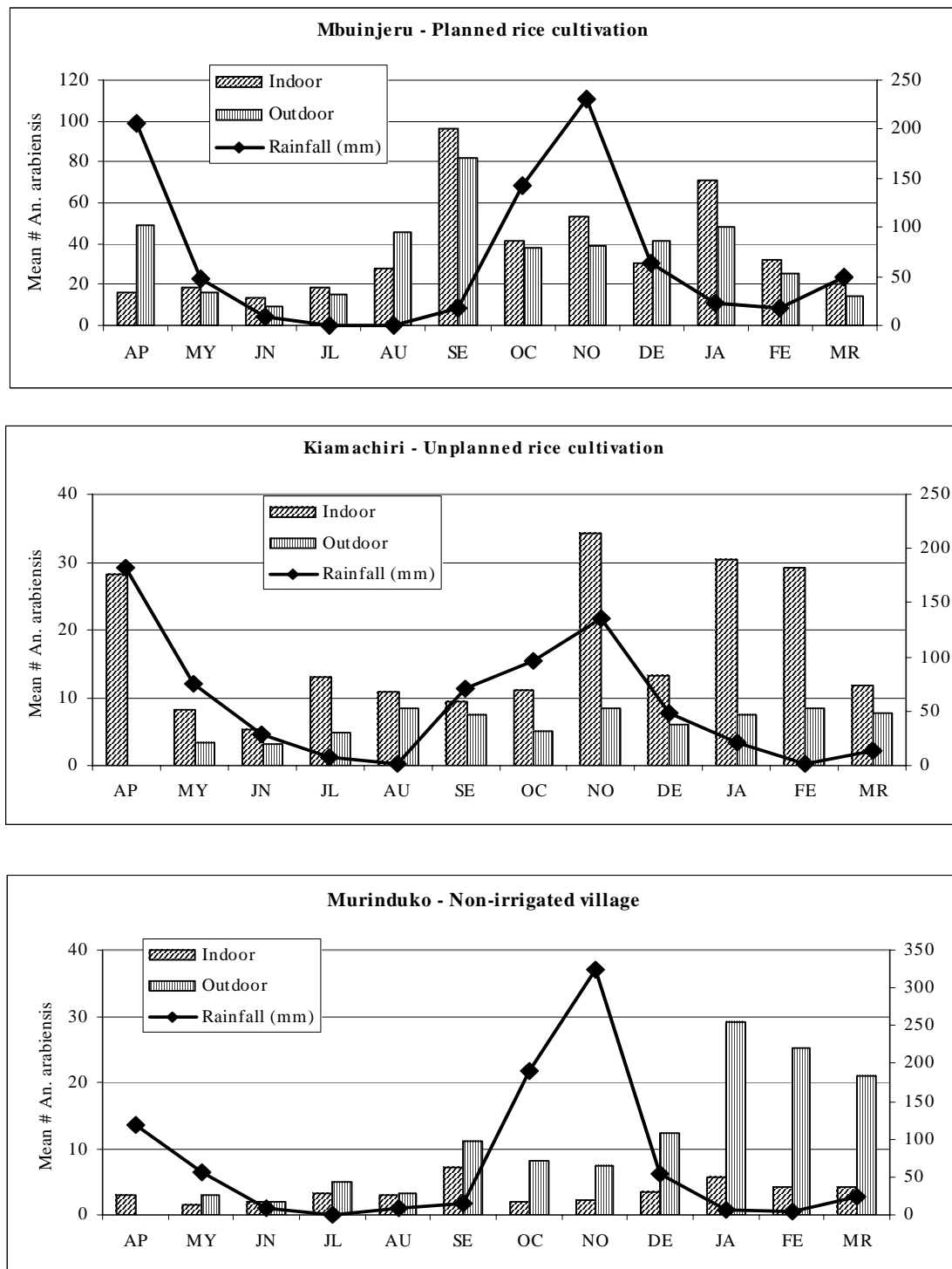
*Identification not done based on available keys. Values in parentheses represent percent of total collections.

Table 2. Species diversity and evenness in three agroecosystems in Mwea, Kenya (April 2004 – March 2005).

		Anopheline species	Non- anopheline mosquito species	All mosquito species
Shannon's Diversity Index (<i>H</i>)	Planned rice agroecosystem (Mbuijeru)	0.484 (6)*	0.209 (11)	1.040 (17)
	Unplanned rice agroecosystem (Kiamaciri)	0.197 (8)	0.469 (14)	0.968 (22)
	Non-irrigated agroecosystem (Murinduko)	1.074 (7)	0.519 (13)	1.507 (20)
Shannon's Equitability (<i>EH</i>)	Planned rice agroecosystem (Mbuijeru)	0.270 (6)	0.202 (11)	0.367 (17)
	Unplanned rice agroecosystem (Kiamaciri)	0.101 (8)	0.073 (14)	0.313 (22)
	Non-irrigated agroecosystem (Murinduko)	0.552 (7)	0.415 (13)	0.503 (20)

* The values in parentheses represent the number of species collected in the survey.

Figure 1. Temporal distribution of *An. arabiensis* relative abundance to monthly rainfall in the three agroecosystems in Mwea, Kenya, April 2004 to March 2005.



pharoensis did not show any significant association with rainfall in any of the three agroecosystems. Other species observed to vary in their monthly density were *Cx. Annulioris* in the unplanned rice agroecosystem and *Ae. cumminsi* in the non-irrigated agroecosystem. However, they were not significantly associated with rainfall ($P > 0.05$).

Larval habitat diversity

The larval habitats identified in the three agroecosystems included irrigation canals, paddies, dams, ditches, hoof prints, marshes, burrow pits, temporary pools, quarry, seeps, swamps, tire tracks, water reservoirs, streams, springs, and rock pools. The greatest diversity of larval habitat types was observed in the non-irrigated agroecosystem (15) followed by the planned rice agroecosystem (13). Only eight habitat types were identified in the unplanned rice agroecosystem.

DISCUSSION

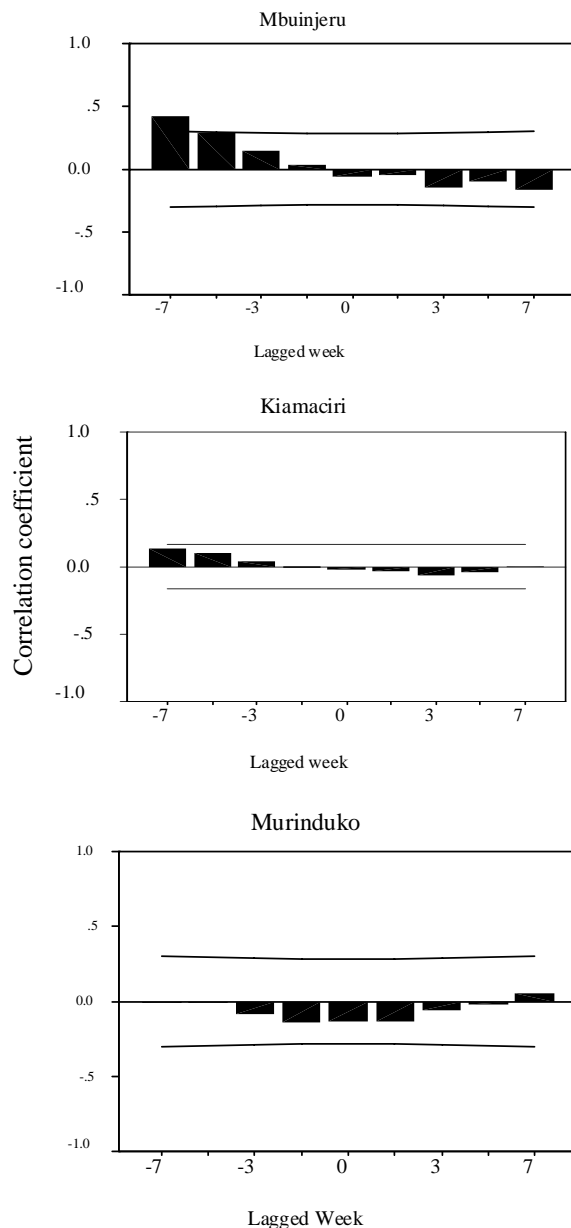
Among the 25 mosquito species observed in this study, 16 have been recorded previously in Kenya (Beier et al. 1990, Ijumba et al. 1990, Reiter et al. 1998) and with the exception of *An. moucheti*, all the anopheline species observed have also been documented previously in the study area (Ijumba et al. 1990). Similarly, out of the ten species recorded in an irrigated area in northern Tanzania, nine were observed in this study (Ijumba et al. 2002). Eleven of the species identified in this study are known vectors of medical importance in Africa. In Mwea, *An. gambiae s.l.* and *An. funestus* are the major vectors of malaria (Ijumba et al. 1990, Mutero et al. 2004a) and are also known vectors of O'nyong-nyong virus and bancroftian filariasis in East Africa (Williams et al. 1965, Pedersen and Mukoko 2002). *Culex quinquefasciatus* transmits bancroftian filariasis and, together with *An. coustani*, *An. maculipalpis*, *Aedes aegypti* Linnaeus, *Aedes Africanus* Theobald, and *Cx. poicilipes*, it is also a vector of West Nile Virus. *An. coustani*, *An. pharoensis*, *Cx. poicilipes*, *Mansonia Africana*, *Ae. cumminsi*, and *Ae. circumluteolus* Theobald are important in transmission of Rift Valley Fever virus (Logan et al. 1991, Gordon et al. 1992, Fontenille et al. 1998, Reiter et al. 1998, Diallo et al. 2000). McIntosh (1972) reported that a vector species infected with RVF virus can infect domestic animals in which the virus amplification occurs, leading to propagation into various other species capable of transmitting the virus to a wider area beyond the area of original outbreaks. In addition, arboviral outbreaks are associated with high vector densities (Lincithicum et al. 1999). Due to the occurrence of high density of vector mosquitoes in the study area, arboviral epidemics could easily be initiated in the area by the arrival of a single viremic human (Reiter et al. 1998) and each of the 25 mosquito species observed could easily become potential vectors. Studies have shown that rice cultivation creates wealth in local communities (Robert et al. 1985) and this is likely to attract people from other areas who may serve as sources of viral infections. Considering that malaria is already a public health problem in the area (Mutero et al. 2004b), the likely effect of introduction of arboviral infections and probably filariasis in the area would be detrimental. This is more so

because, as witnessed during the El Nino/Southern Oscillation phenomenon, arboviral outbreaks are compounded by outbreaks of other diseases including malaria and cholera resulting in high mortality rates primarily from multiple infections (Anyamba et al. 2001). The epidemiological significance of the diverse mosquito species observed in the study area should therefore not be underestimated. Importantly, the mosquito species composition in the area could be higher than was captured in this study. We used two mosquito sampling methods only and this could have been biased against a wide range of mosquitoes, especially aedines which tend to be active diurnally (Miller et al. 2000). A more comprehensive study targeting the diverse mosquito biology is being undertaken.

A significant variation in mosquito density and species richness was observed in the three agroecosystems. These variations may be due to the observed differences in the diversity of aquatic habitats among the three villages. The non-irrigated agroecosystem had more diverse habitat types, thereby supporting diverse mosquito species. Previous studies have reported a positive relationship between habitat type diversity and mosquito species richness (Beier et al. 1990; Shililu et al. 2003). The majority of the habitats in the non-irrigated agroecosystem were temporary and parched during the dry season, thus accounting for the low mosquito densities. In rice agroecosystems, irrigated rice fields and associated habitats such as irrigation channels and seepage areas are the principal mosquito larval habitats (Mutero et al. 2000) and continue to support mosquito populations during the dry season when the other larval habitats are dry. All rice fields in planned rice agroecosystems are transplanted simultaneously and are therefore homogenous across a wide area. In contrast, unplanned rice fields are transplanted at different times due to variations in water availability, the practice of single or double cropping and other economic factors that affect the small scale farmers. As a result, rice phenology is usually heterogeneous representing different stages of rice development at any given time. Consequently, unplanned rice fields are expected to support a wide spectrum of mosquito species since the ideal breeding conditions for different species are present at any given time (Klinkenberg et al. 2003). This was, however, not apparent in our study probably because the area under rice in the unplanned rice agroecosystem was 4-fold lower than in the planned rice agroecosystem. Additionally, more larval habitats were identified in the planned than in the unplanned rice agroecosystem.

Mosquito species that utilize rice fields as breeding grounds were found in significantly higher densities in rice agroecosystems. For instance *An. gambiae s.l.*, *An. pharoensis*, and *Cx. quinquefasciatus* which are important riceland mosquitoes (Lacey and Lacey, 1990, Mutero et al. 2000, Klinkenberg et al. 2003) were captured in significantly higher densities in rice agroecosystems than in the non-irrigated agroecosystem. Cross-correlation analysis further confirmed that mosquito production in the rice agroecosystems was least dependent upon rainfall, an indication that it is most likely influenced by rice cultivation (Mutero et al. 2004b). A proper

Figure 2. Cross-correlation between mean density of *Anopheles arabiensis* and rainfall in the three villages in Mwea, Kenya. The X-axis represents time lag in weeks between mosquito samples and rainfall, April 2004 to March 2005. Horizontal lines indicate the confidence limits.



understanding of the relationship between rice phenology and mosquito density and species succession would facilitate proper timing of vector control operations and is one of the objectives of our ongoing studies. Our results further confirmed previous findings that rice areas are unsuitable for *An. funestus* (Ijumba et al. 2002, Klinkenberg et al. 2003, Mutero et al. 2004a) except in western Kenya (Githeko et al. 1993) and in the plateaus of Madagascar (Marrama et al. 1995). Little is known about *An. coustani* and *An. maculipalpis*, but they have been previously found occurring in low numbers both in rice (Mukiama and Mwangi 1989, Ijumba et al. 1990) and non-rice agroecosystems (Ijumba et al. 2002). Aedines, on the other hand, have

frequently been reported in human landing and CDC light trap collections but in low numbers (Mwandawiro et al. 1997, Miller et al. 2000).

Although rice cultivation provides a source of livelihood, it also exposes communities to the risk of mosquito-related diseases. To enhance agricultural production while at the same time avoiding negative effects on public health, a closer collaborative action between health and agriculture sectors in planning and execution of irrigation schemes is required in order to reduce vector density. Because Mwea is currently targeted for microbial control of immature stages of malaria vectors, there is an opportunity to increase the benefits of the program by targeting all mosquito species present in the area. This will not only reduce the risk of mosquito-borne diseases but will also be appreciated by the community since biting nuisance will also be reduced. Studies on the ecology of the diverse mosquito species identified within the study area, including their relationship with rice cultivation, their host preference, and their potential to transmit malaria and arboviruses, are being undertaken.

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