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DIVERSITY OF RICELAND MOSQUITOES AND FACTORS AFFECTING THEIR OCCURRENCE AND DISTRIBUTION IN MWEA, KENYA

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ABSTRACT. Knowledge of mosquito species diversity, occurrence, and distribution is an essential component of vector ecology and a guiding principle to formulation and implementation of integrated vector management programs. A 12-month entomological survey was conducted to determine the diversity of riceland mosquitoes and factors affecting their occurrence and distribution at 3 sites targeted for malaria vector control in Mwea, Kenya. Adult mosquitoes were sampled indoors by pyrethrum spray catch and outdoors by the Centers for Disease Control and Prevention light traps. Mosquitoes were then morphologically identified to species using taxonomic keys. The characteristics of houses sampled for indoor resting mosquitoes, including number of people sleeping in each house the night preceding collection, presence of bed nets, location of the house, size of eaves, wall type, presence of cattle and distance of the house to the cowshed, and proximity to larval habitats, were recorded. Of the 191,378 mosquitoes collected, 95% were identified morphologically to species and comprised 25 species from 5 genera. Common species included *Anopheles arabiensis* (53.5%), *Culex quinquefasciatus* (35.5%), *An. pharoensis* (4.7%), *An. coustani* (2.5%), and *An. funestus* (1.6%). Shannon's species diversity and evenness indices did not differ significantly among the 3 study sites. There was a marked house-to-house variation in the average number of mosquitoes captured. The number of people sleeping in the house the night preceding collection, size of eaves, distance to the cowshed, and the nearest larval habitat were significant predictors of occurrence of either or both *An. arabiensis* and *Cx. quinquefasciatus*. The peak abundance of *An. arabiensis* coincided with land preparation and the first few weeks after transplanting of rice seedlings, and that of *Cx. quinquefasciatus* coincided with land preparation, late stage of rice development, and short rains. After transplanting of rice seedlings, the populations of *Cx. quinquefasciatus* were collected more outdoors than indoors, suggesting a shift from endophily to exophily. These results demonstrate that irrigated rice cultivation has a strong impact on mosquito species occurrence, distribution, abundance, and behavior, and that certain house characteristics increase the degree of human–vector contact.

KEY WORDS Irrigation, rice, mosquito species, mosquito-borne disease

INTRODUCTION

In most African countries, human population growth outpaces agricultural production (Vorosmarty et al. 2000). In an effort to boost food production to feed this population, water development projects have been introduced and the area under irrigated agriculture extended (Keiser et al. 2004). Unfortunately, irrigated agriculture, especially rice cultivation, creates aquatic habitats that support prodigious numbers of diverse mosquito species, including vectors of malaria, filariasis, and arboviruses as well as nuisance species (Muturi et al. 2006). As a result, numerous studies have demonstrated a strong link between irrigation development and increased prevalence of malaria (Ghebreyesus et al. 1999), Bancroftian filariasis (Mawuli et al. 1999), and arboviruses (Diallo et al. 2005).

In order to minimize the risk of mosquito-borne diseases and associated economic loss in irrigated areas, there is an urgent need to control mosquito vectors. Integrated vector management (IVM) is considered the best approach of reducing mosquito densities, especially in a rice agro-village complex where large bodies of water exist (Lacey and Lacey 1990). The concept of integrated pest management was first proposed by Stern et al. (1959) for management of crop pests but is also adaptable to arthropod public health pests (Metcalf and Novak 1994). As an applied ecological approach, IVM relies on packages of evidence-based interventions, tailored to suit the local settings to control, manage, and monitor vector-borne diseases at all relevant points in the life cycle and transmission cycle of the vector, with minimum negative effect on the environment and human health (Novak and Lampman 2001). In particular, IVM requires proper understanding of the complex interrelations between various components of disease transmission (Metcalf and Novak 1994). Studies have shown that even within a single community, there exists house-to-house variation in mosquito densities and degree of disease transmission as a result of differences not only in characteristics of the houses and their inhabitants but also in levels of

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elevation, water table, and proximity to larval habitats and alternative hosts (Minakawa et al. 2002, Rwegoshora et al. 2007). Identifying the driving forces that determine when and where a particular mosquito species occurs is therefore an essential component of mosquito-borne disease management.

Most entomological studies in East African rice agro-ecosystems have mainly focused on major malaria vectors with little attention to other mosquito species. The only detailed studies on riceland mosquito species diversity are those by Chandler and Highton (1975, 1976), Chandler et al. (1975, 1976), and Surtees et al. (1970) in Ahero Rice Scheme, Muturi et al. (2006) in Mwea Rice Scheme, Kenya, and Ijumba et al. (2002) in lower Moshi, Tanzania. The paucity of information on riceland mosquito species diversity has made formulation and implementation of IVM programs difficult. The result has been emergence of arboviral diseases previously thought to be effectively controlled or unimportant (Gubler 1996) and changes in transmission dynamics of malaria and Bancroftian filariasis (Keiser et al. 2004, Erlanger et al. 2005).

Identifying diverse mosquito species occurring in a riceland agro-ecosystem is an essential prerequisite for understanding the ecology of disease vectors, which is the guiding principle for implementation of an IVM program. The objective of this research was to determine the relative abundance and spatiotemporal distribution of indoor- and outdoor-collected adult mosquitoes, and the factors affecting house-to-house variation in mosquito densities at 3 agro-village complexes targeted for large-scale implementation of malaria vector control in Mwea Rice Irrigation Scheme, Kenya.

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 in detail elsewhere (Mutero et al. 2004, Muturi et al. 2007). The Mwea Irrigation Scheme is located in the west-central region of Mwea division and covers an area of 13,640 ha. More than 50% of the scheme area is used for irrigated rice cultivation and the remaining area is used for subsistence farming, grazing, and community activities.

Three ecologically identical villages within the irrigation scheme—Kangichiri, Kiuria, and Rurumi—were randomly selected for the study. Kangichiri and Kiuria are adjacent to each other and Rurumi is approximately 7 km east of Kiuria. Kangichiri and Kiuria are located at the central-west region of the scheme and have approximately 150 and 222 homesteads, respectively, with more than 650 residents in each village. Rurumi is located northwest of the scheme and has 261 homesteads and more than 920 residents. Cows, goats, chickens, and donkeys are the primary domestic animals in all 3 villages. These animals are kept within 5 m of most houses. More than 90% of the houses are semipermanent, with mud walls and iron roofing. More than 75% of each village land is under rice cultivation and human habitation occupies the remaining area, with less than 10% utilized for vegetables and bananas. The rice cropping schedule in these villages is guided by the water distribution scheme as determined by the National Irrigation Board. Many species of birds and mammals in the surrounding areas visit the rice fields for feeding and are generally considered as temporary or ephemeral inhabitants that can act as intermediate hosts for arboviruses.

Rice cropping practice

The typical rice farming practices include land preparation, nursery preparation, transplanting, fertilizer application, field maintenance, preharvesting drainage, and harvesting. Land preparation begins in July and involves flooding, rotavation, and leveling of the paddies, followed by nursery sowing. Transplanting is usually done 4 wk after nursery sowing (August). The level of water in the paddies is increased to a depth of 10 cm immediately after transplanting. The rice plants pass through several stages, including vegetative phase lasting 7–9 wk, reproductive phase lasting 4–6 wk, and ripening phase lasting 4 wk. The period between transplanting and harvesting lasts from August to November, followed by a postharvest period in December. The 2nd crop if planted is cultivated prior to the long rains between January and May. *Anopheles arabiensis* Patton and *Culex quinquefasciatus* Say are the dominant mosquito species in the area (Muturi et al. 2006), the former being the main vector of malaria and the only sibling species of the *An. gambiae* Giles s.l. in the area (Mutero et al. 2004), and the latter is a potential vector of filariasis and arboviruses and a major nuisance mosquito species in the area (Muturi et al. 2006).

Meteorological data

In each of the 3 villages, rainfall data were recorded daily over a period of 12 months (March 2005 and February 2006). Temperature and relative humidity for each village were also taken using temperature and relative humidity data loggers (Onset Computer Corporation, Bourne, MA).

Mosquito sampling

Adult mosquitoes were sampled weekly in 30 randomly selected houses in each of the 3 study sites between March 2005 and February 2006. 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 (0700–1100 h) to collect indoor resting mosquitoes using pyrethrum spray catch (PSC) method (WHO 1975). White sheets were spread on the floor of the whole house and the house was sprayed with 0.3% pyrethrum in water. All knocked-down mosquitoes were collected in petri dishes and transported to the laboratory for identification. Along with mosquito collection, the number of people sleeping in each house the night preceding collection was recorded. Other variables recorded include presence of bed nets, location of the house (center or periphery of the village), size of eaves, wall type, presence of cattle, distance of the house from the cowshed, and the nearest larval habitat. Concurrent with PSC, 6 Centers for Disease Control and Prevention (CDC) light traps (J.W. Hock Ltd., Gainesville, FL) were run outdoors twice per week for 2 consecutive nights in each village between 1800 and 0700 h. The traps were distributed equally in 3 locations in the village: center, periphery, and 200 m from the village periphery. The mosquitoes were subsequently identified morphologically to species (Edwards 1941, Gillies and Coetzee 1987).

Statistical analyses

Data were analyzed using SPSS version 11.5 statistical package (SPSS, Inc., Chicago, IL). The relationship between adult mosquito counts and rainfall was compared using Pearson correlation analysis. Multiple logistic regression analysis was used to compare the relationship between the measured micro-epidemiological factors and occurrence of mosquito species. Species diversity and evenness at the 3 study sites was determined using Shannon's species diversity and evenness indices (Magurran 1988, Rosenzweig 1995). The differences in species diversity and evenness at the 3 sites were compared using analysis of variance. Mosquito counts were log-transformed before analysis to normalize the data.

RESULTS

Species composition and abundance

In total, 191,378 mosquitoes were collected indoors and outdoors at the 3 study sites during the 12-month study period. These comprised 115,798 anophelines and 75,580 culicines. Anophelines comprised 92% (n = 79,376) of indoor-collected mosquitoes and culicines formed 62% (n = 112,002) of outdoor-collected mosquitoes. Ninety-five percent (182,644) of the total mosquitoes collected were identified to species by morphological characters. These yielded 25 mosquito species from 5 genera. The genus *Anopheles* was the most diverse with 9 species, followed by *Aedes* with 7 species, *Culex* with 4 species, *Mansonia* with 2 species, and *Ficalbia* and *Coquilletidia* with 1 species each. Some 230 indeterminate species of genus *Culex* were also collected. All the 25 mosquito species were represented in the CDC light trap collections, compared with 14 species in PSCs (Table 1). *Anopheles arabiensis* and *Cx. quinquefasciatus* were the dominant species, accounting for 89% of the total collections. Other common species included *An. pharoensis* Theobald (4.7%), *An. coustani* Laveran (2.5%), and *An. funestus* Giles (1.6%). The remainder of the species accounted for only 2.2% of the total collections. *Anopheles arabiensis* comprised 90.2% and 26.1% of indoor- and outdoor-collected mosquitoes, respectively, and *Cx. quinquefasciatus* constituted 7.4% and 56.5% of indoor- and outdoor-collected mosquitoes, respectively. Other species commonly captured outdoors were *An. pharoensis* (8.1%), *An. coustani* (4.4%), *An. funestus* (1.5%), *Cx. annulioris* Theobald (1.4%), and *Cx. poicilipes* Theobald (1.1%) (Table 1).

Species diversity and richness

Shannon's species diversity and equitability indices for the 3 study sites in Mwea, Kenya, are represented in Table 2. The species diversity indices for the 3 sites ranged from 1.00 to 1.27, and species equitability indices ranged from 0.33 to 0.42. Analysis of variance tests did not reveal any significant differences in species diversity and evenness indices among the 3 study sites (F = 0.760 and 1.002, df = 2, 24; $P > 0.05$).

Temporal distribution of common mosquito species in relation to rainfall pattern and rice cropping

The average annual precipitation for the 3 study sites was 837 mm. The rainfall pattern was bimodal, concentrated in April–May and October–November (Fig. 1). Because of water shortage, rice fields in each village were separated into 2 blocks, each comprising rice fields located on 2 sides of the village, and rotavation for each block commenced at different dates. Land preparation commenced in April and ended in June. The fields remained flooded and the final preparation was accomplished in July, followed by transplanting in August 2005, a growing period thereafter, and harvesting in December. Figure 2 shows the population dynamics of *An. arabiensis* and *Cx. quinquefasciatus* relative to monthly rainfall for the 3 study sites combined. Two peak populations were observed among indoor-collected populations of *An. arabiensis*. The first peak occurred in April–May, coinciding with the long rains and

Table 1. Relative abundance of mosquito species collected in the 3 study sites in Mwea, Kenya.[1]

	PSC		CDC light traps	
Species	Total	%	Total	%
Anopheles coustani	4	0.01	4,611	4.41
Anopheles funestus	1,364	1.74	1,528	1.46
Anopheles arabiensis	70,544	90.22	27,245	26.08
Anopheles maculipalpis	0	0.00	13	0.01
Anopheles moucheti	0	0.00	2	0.00
Anopheles nili	14	0.02	20	0.02
Anopheles pharoensis	177	0.23	8,419	8.06
Anopheles pretoriensis	0	0.00	35	0.03
Anopheles rufipes	0	0.00	1	0.00
Aedes aegypti	0	0.00	5	0.00
Aedes circumluteolus	2	0.00	98	0.09
Aedes cumminsi	41	0.05	390	0.37
Aedes metallicus	0	0.00	1	0.00
Aedes furcifer-taylori[2]	15	0.02	156	0.15
Aedes vittatus	0	0.00	1	0.00
Aedes woodi	0	0.00	2	0.00
Coquilletidia fuscopennata	0	0.00	1	0.00
Culex annulioris	151	0.19	1,425	1.36
Culex poicilipes	60	0.08	1,127	1.08
Culex quinquefasciatus	5,805	7.42	58,984	56.47
Culex tigripes	3	0.00	24	0.02
Culex spp.	5	0.01	225	0.22
Ficalbia plumosa	2	0.00	4	0.00
Mansonia africana	0	0.00	103	0.10
Mansonia uniformis	0	0.00	37	0.04
Total	78,187	100.00	104,457	100.00

[1] PSC, pyrethrum spray catch; CDC, Centers for Disease Control and Prevention.

[2] *Aedes furcifer* and *Ae. taylori* are morphologically indistinguishable and hence treated as *Ae. furcifer-taylori.*

land-preparation phase, while the second and the highest peak was observed in September, a period characterized by low rains and rice seedling post-transplanting period. Outdoors, a progressive decrease in *An. arabiensis* populations occurred between March and July, followed by a sharp increase thereafter with a peak in September and a pattern similar to that of indoor populations thereafter. The temporal changes in the counts of both indoor- and outdoor-collected *Cx. quinquefasciatus* were similar between March and July, with peaks in March and May. However, although indoor populations of *Cx. quinquefasciatus* continued to decrease in subsequent months, that of outdoor populations increased sharply, reaching a peak in November, a period coinciding with late stage of rice development and short rains. Two peak populations of outdoor-collected *An. pharoensis* were evident, the first occurring in June and the second in November. According to Pearson correlation analysis results, only the indoor-collected *Cx. quinquefasciatus* were significantly correlated with rainfall ($r = 0.722$, $P < 0.05$).

House-to-house variation in mosquito density

There was a marked house-to-house variation in the average number of indoor resting *An. arabiensis* and *Cx. quinquefasciatus* collected at the 3 study sites during the 12-month study period (Fig. 2). Even adjacent houses sometimes differed markedly in mosquito capture rates. In Kangichiri for instance, the average number of

Table 2. Mosquito species diversity and evenness in the 3 study sites in Mwea, Kenya.

Index	Study site	Anophelines	Culicines	All species
Shannon's diversity index	Kangichiri	0.55 (8)[1]	0.45 (13)	1.00
	Kiuria	0.61 (8)	0.46 (11)	1.07 (19)
	Rurumi	0.74 (7)	0.53 (13)	1.27 (20)
Shannon's equitability	Kangichiri	0.26 (8)	0.18 (13)	0.33
	Kiuria	0.29 (8)	0.19 (11)	0.36 (19)
	Rurumi	0.38 (7)	0.20 (13)	0.42 (20)

[1] The values in parentheses represent the number of species collected in the survey.

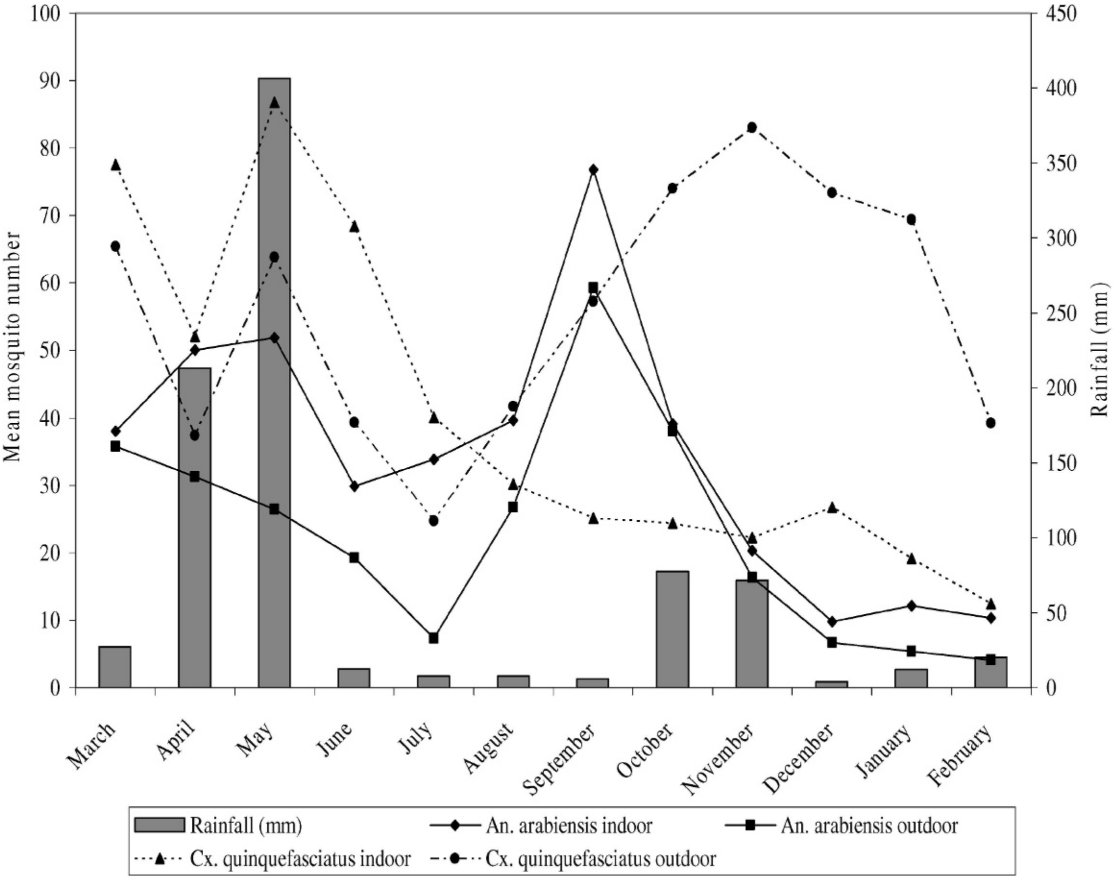

Fig. 1. Summary of the monthly mosquito density relative to rainfall pattern, March 2005–February 2006.

indoor resting *Cx. quinquefasciatus* and *An. arabiensis* collected in house 94 was 1.77 and 55.59, respectively, compared with 0.14 for *Cx. quinquefasciatus* and 4.57 for *An. arabiensis* in house 97 located only 10 m away. In Rurumi, the average number of indoor resting *Cx. quinquefasciatus* and *An. arabiensis* collected in house 143 was 0.00 and 7.75, respectively, and that of house 144 only 6 m apart was 5.93 for *Cx. quinquefasciatus* and 43.58 for *An. arabiensis.* These houses differed markedly in the design of construction (e.g., numbers and size of eaves), number of occupants, livestock ownership, and distance to the larval habitat(s).

Multiple logistic regression analysis was used to determine the relationship between the measured household characteristics and mosquito species occurrence (Table 3). *Culex quinquefasciatus* was positively associated with the size of eaves and the number of people sleeping in the house the night preceding collection and negatively associated with the distance to the nearest larval habitat. *Anopheles arabiensis* was encountered more in houses with large eaves, farther away from the cowshed, and closer to the larval habitats.

DISCUSSION

This study confirmed the occurrence of 25 mosquito species in Mwea Rice Irrigation Scheme in central Kenya. Our previous study in the same area using the same sampling techniques reported the presence of 17 mosquito species in a rice–village complex compared with 25 species in a nonirrigated village (Muturi et al. 2006). However, it was interesting to note that some species collected in this earlier study were not observed in the current study and vice versa. This indicates that the actual number of mosquito species occurring in the area may be higher than that observed in these studies and calls for a more detailed mosquito survey using a collection of sampling techniques over a longer time frame. A combination of sampling techniques targeting both the larvae and adults increases the diversity of mosquito species captured (Chandler and Highton 1975, Chandler et al. 1975, Snow 1983, Rajavel et al. 2005).

The results further demonstrated similarities in species diversity and evenness among the 3 study sites, justifying their choice as replicates for implementation of the pilot mosquito control

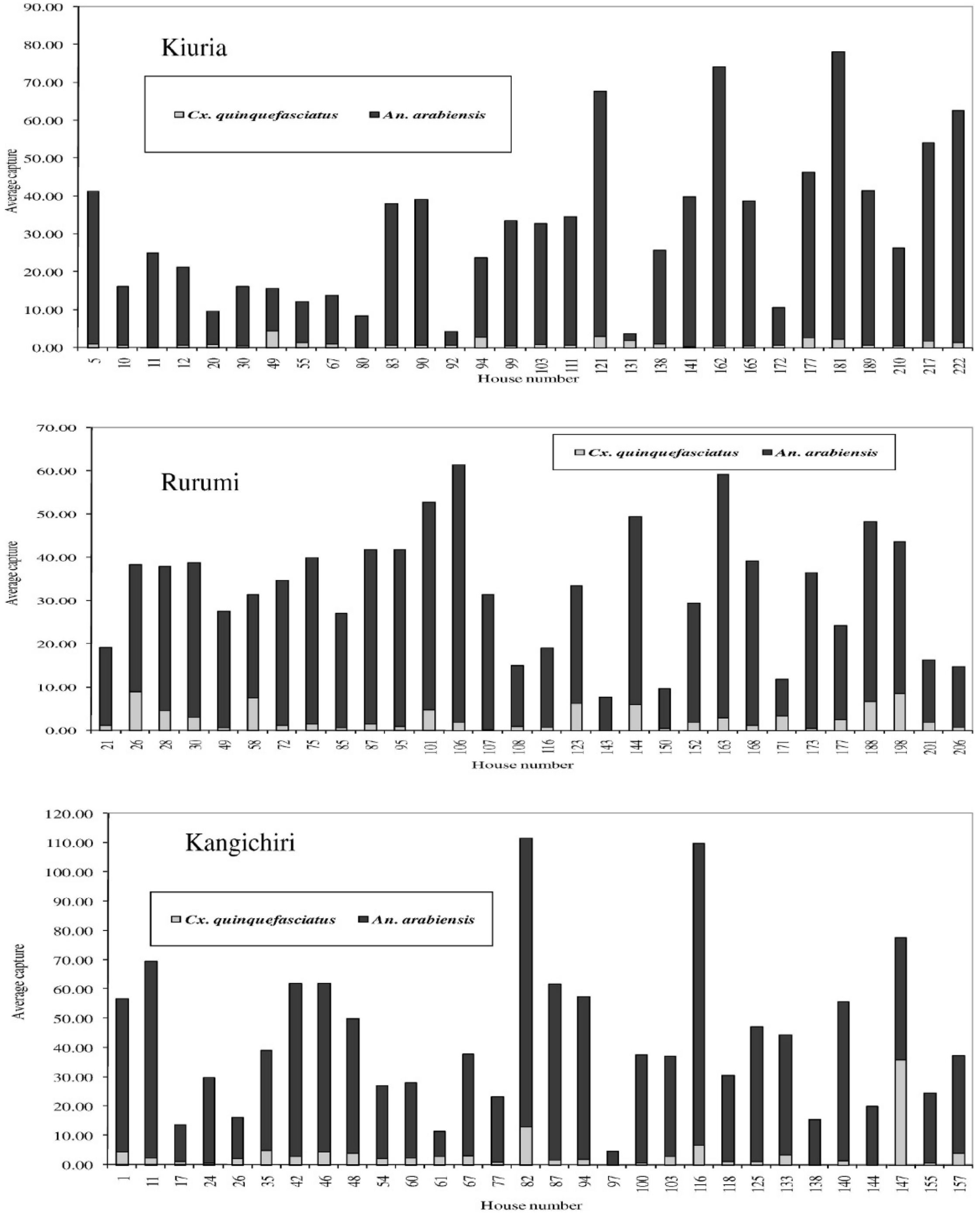

Fig. 2. House-to-house variation in the mean number of indoor resting mosquitoes captured during the 12-month study period.

program. Mosquitoes were inequitably distributed in all 3 villages, *An. arabiensis* and *Cx. quinquefasciatus* forming the bulk of the collection. This would be expected because the 3 study sites are surrounded by rice fields where the 2 species thrive in prolific numbers (Muturi et al. 2007). Moreover, each homestead had a wet pit latrine that may have provided additional larval habitats for *Cx. quinquefasciatus* (Maxwell et al. 1990). The rarity of majority of mosquito species

Table 3. Multiple logistic regression analyses showing the relationship between indoor occurrence of mosquito species and house characteristics.

	Cx. quinquefasciatus			*An. arabiensis*		
Characteristic	Coefficient	df	*P*	Coefficient	df	*P*
No. of sleepers	0.17	1	0.04	0.13	1	0.10
Presence of animals	−21.06	1	1.00	18.51	1	1.00
Distance to the nearest animal shed	0.01	1	0.56	0.08	1	0.04
Wall type	−0.38	3	0.06	−17.82	3	0.11
Size of eaves	0.10	1	0.03	0.10	1	0.00
Presence of bed nets	−0.42	1	0.21	−18.83	1	1.00
House location	0.06	1	0.63	0.89	1	0.09
Distance to the nearest aquatic habitat	−0.10	1	0.01	−1.01	1	0.00

captured at the expense of *An. arabiensis* and *Cx. quinquefasciatus* demonstrate the significant impact of rice cultivation on mosquito species richness, abundance, and distribution. Irrigated rice cultivation can increase or decrease the prevalence of a particular mosquito species in an area through creation or destruction of preferred larval habitats. In the arid Kunduz Valley of northern Afghanistan, contaminants resulting from irrigation development resulted in elimination of *An. superpictus* Grassi, formerly the most important vector in the area, and the rise of *An. pulcherrimus* Theobald and *An. hycanus* Wiedmann and consequent increase in vivax malaria from 5% to 20% in some villages (Buck et al. 1972). In Sri Lanka, developmental changes from forest, through settlement, and development of Mahaweli Irrigation Project resulted in a 20% decrease in mosquito species richness, from 49 species in the forested phase to 39 by the 3rd year under irrigation (Amerasinghe and Munasingha 1988a, 1988b; Amerasinghe and Ariyasena 1990, 1991; Amerasinghe and Indrajith 1994). The vast area covered by rice fields reduces the amount of land available to support diverse mosquito larval habitats such as rain pools, rock pools, marshes, swamps, ditches, ponds, tree holes, and hoofprints. Consequently, species that are unable to colonize and thrive in rice fields and associated habitats may be less abundant or absent in rice agro-ecosystems.

The rice cropping cycle had significant impact on temporal distribution and abundance of *An. arabiensis*, *An. pharoensis*, and *Cx. quinquefasciatus*. In addition, rainfall also significantly impacted the distribution and abundance of *Cx. quinquefasciatus*. Rainfall has been reported to be insignificant in determining mosquito abundance within Mwea Rice Irrigation Scheme (Asimeng and Mutinga 1993, Muturi et al. 2006). The critical periods for *An. arabiensis* were land preparation and early stage of rice development, and *Cx. quinquefasciatus* was closely linked with land preparation, late stage of rice development, and rainfall. *Anopheles pharoensis* populations coincided with the end of long rains and late stage of rice growth. A similar trend was observed in Ahero Irrigation Scheme, Kenya, and in Bansang area in the Gambia (Chandler and Highton 1975, Snow 1983). The numerous open, sunlit pools created by footprints of rice workers during transplanting and fertilizer applications favor the breeding of *An. gambiae* s.l. (Chandler and Highton 1976). As the rice canopy cover increases, *An. gambiae* s.l. continue to breed around the edges of rice fields but at much lower densities because of restricted optimal habitat and increased predator levels. However, some *Culex* spp. thrive well in established rice stands containing a variety of other aquatic flora and fauna (Snow 1983). Understanding the relationship between the rice cropping cycle, rainfall, and mosquito species distribution and abundance would therefore facilitate formulation of species-specific vector control programs.

The average number of indoor resting mosquitoes varied markedly even among houses close to each other. Multiple logistic regression analysis results identified 3 categories of factors to be significantly associated with mosquito species occurrence in the houses. First, both *Cx. quinquefasciatus* and *An. arabiensis* were more likely to occur in poorly constructed houses with large holes and openings. Second, both species were also more likely to occur in houses closer to a larval habitat. In addition, houses farther away from cowsheds were more likely to be inhabited by *An. arabiensis*. Minakawa et al. (2002) working in western Kenya demonstrated that anophelines tend to inhabit houses around larval habitats. Ijumba et al. (1990) and Mutero et al. (2004) conducted blood meal analysis for *An. arabiensis* in Mwea, Kenya, and obtained a 1:1 ratio for human:bovine blood meals. Because cattle are kept outdoors in all 3 study sites, they are more likely accessible than are humans to *An. arabiensis* and may have diverted this species from entering the houses. Finally, houses with many occupants were more likely to contain *Cx. quinquefasciatus* than those with fewer occupants.

Mosquitoes use olfactory cues to locate their host, and body odors from many people can attract more mosquitoes than odors from 1 or few people (Rwegoshora et al. 2007).

A shift from endophily to exophily was observed among *Cx. quinquefasciatus* populations after rice transplanting henceforth. The higher mosquito densities associated with rice seedlings transplanting and the short rains may have encouraged the use of insecticide-treated bednets (ITNs) and other vector control measures to minimize the biting nuisance. Continued use of ITNs may have caused a shift from indoor to outdoor resting by *Cx. quinquefasciatus*. A reduction in the average number of indoor resting culicines has been reported previously following the introduction of ITNs (Lindblade et al. 2006). A shift from indoor to outdoor resting would occur more readily for *Cx. quinquefasciatus* in the study area, considering its low preference for human blood meals (Muturi et al. 2008). Along the Kenyan coast, this species shifted from 93.1% anthropophily to 85.2% ornithophily after introduction of ITNs (Bogh et al. 1998). The large numbers of domestic animals in the study area and the high populations of birds that were associated with rice transplanting and panicle initiation stages of rice development ensured that this species had easy access to blood meals. This illustrates the need to evaluate the role that *Cx. quinquefasciatus* may play in transmission of arboviruses in similar areas.

The negative impact of *An. arabiensis* and *Cx. quinquefasciatus* on human health is widely acknowledged in many parts of Africa. Both species are major vectors of Bancroftian filariasis in irrigated and nonirrigated agro-ecosystems (Bogh et al. 1998, Keiser et al. 2004). In addition, *An. arabiensis* is a major vector of malaria in the study area and other irrigated rice agro-ecosystems in East Africa (Mutero et al. 2004). *Anopheles funestus*, also an important vector of malaria and Bancroftian filariasis in Africa, does not do well in African rice agro-ecosystems except in western Kenya and in the plateaus of Madagascar (Githeko et al. 1993, Marrama et al. 1995). *Anopheles funestus*, together with the other infrequent mosquito species, may seem insignificant in disease transmission in the area. However, management of the most dominant species alone may be ineffective in control of mosquito-borne disease because a more efficient but less abundant species may sustain disease transmission (Charlwood et al. 1997). This underscores the need to integrate the management of all mosquito species present in similar areas other than targeting selected vector species.

The findings of this study have demonstrated a strong relationship between irrigated rice cultivation and mosquito species occurrence, distribution, abundance, and behavior. The study has also identified some micro-epidemiological factors underlying house-to-house variation in distribution of mosquito species in a rice–village complex. As the human populations continue to increase, the demand for food and the need to develop more water development projects has become apparent. Concerted efforts should be made to reduce the density of mosquitoes in these areas in order to counter the problem of mosquito-borne diseases. Further studies are ongoing to establish the relative contribution of diverse larval habitats to mosquito productivity in the area.

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